

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY



SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING MECHANICAL SYSTEMS AND VEHICLE ENGINEERING PROGRAM

DESIGN AND ANALYSIS OF MANUALLY DRIVEN AND ENGINE POWERED WHEAT CROP REAPER FOR BROAD BED FURROWS

Thesis Submitted to the Mechanical Systems and Vehicle Engineering Program for partial fulfillment of the requirement for the Award of Master of Science Degree in Agricultural Machinery Engineering

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Adama, Ethiopia

CANDIDATE’S DECLARATION

I hereby declare that the work which is being presented in the thesis entitled “Design and Analysis of Manually Driven and Engine Powered Wheat Crop Reaper for Broad Bed Furrows” for partial fulfillment of the requirements for the Award of the Degree of Master of Science in Agricultural Machinery Engineering is an authentic record of my work carried out from March 2016 to June 2017 under the supervision of Dr.-Ing. Simie Tola, Department of Mechanical Systems and Vehicle Engineering Program, Adama Science and Technology University, Ethiopia.

The matter embodied in this thesis has not been submitted by another person for the award of any other degree or diploma. All relevant resources of information used in this thesis have been fully acknowledged.

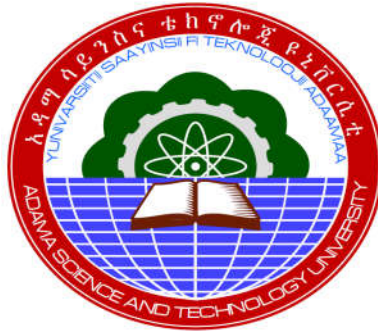
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This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief. All sources of materials used for this thesis work have been fully acknowledged. This thesis has been submitted for examination with my approval.

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BY

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DEDICATION

This thesis is dedicated to my Mother and Father, who sacrificed much to bring me up to this level and to my lovely sisters, brothers and their families for the devotion they made to make my life successful.

AUTHOR BIOGRAPHY

The author was born on April 3, 1989 in Oromia Regional State, East Shoa Zone, and Lume District from his father Belay Teferi and his mother Tirunesh Dinku. He attended his elementary Education at Haro-Gumbu Primary School, Grade 1-4, and Grade 5-7 at Ejere Elementary and Junior School and Grade 8 at Bole Elementary school

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LIST OF ABBREVIATIONS AND ACRONYMS

BBF	Broad Bed Furrow
BBM	Broad Bed Maker
CSA	Central Statistical Authority
F _c	Cutting force in the cutter bar
F _f	Frictional force in the cutter bar
F _i	Inertia force in the cutter bar
GDP	Gross Domestic Product
ha	hectare
IRRI	International Rice Research Institute
kNm	Kilo Newton Meter
kW	kilo watt
MPa	Mega Pascal
MS	Sheet Metal
rad	Radian
rpm	Revolution per meter
SAA	Sasakawa Africa Association
μm	micro meter
ρ	density
τ	shear strength

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ABSTRACT

Harvesting, an important field operation for any food grain crops, is the cutting process carried out when the crop attains physiological maturity such that a maximum recovery of quality product is obtained. Harvesting operation has to be done at a particular period but in shorter time. Harvesting by using traditional method is time consuming; it needs much labour force and result in grain loss. Importing combine harvester is too expensive and not affordable for small scale farmers. The aim of the thesis is to design and develop of wheat crop reaper for harvesting wheat crops mainly for furrows prepared by BBM and also for traditional furrows. It is intended to help small scale farmers for harvesting wheat crops efficiently. Main parts of machine component were selected by preparing concept selection based on created selection criteria. Design and design result of each part were included in this paper and material selection for most part based on the availability in Ethiopia. 2D and 3D of different assembled and detail component of a machine was generated by CATIA V5R17 software. The designed reaper was manually driven and powered with diesel engine for cutting wheat crop stems. With the help of pulley-belt arrangement drive power is transmitted from engine to gearboxes. A spur gearbox and a bevel gearbox are used. One end of bevel gear box output shaft was connected to slider crank mechanism which converts rotary motion of shaft into reciprocating motion of cutter bar. Reciprocating cutter bar slides over fixed bar and created scissoring action between cutter blades which were responsible for cutting the wheat crop stems. Collecting mechanism consist of flat belt with collecting lugged plates bolted on it. After completely manufacture the wheat reaper, this machine can be compact and efficient to cut the wheat stems. The reaper is moderately compact and easy to handle. This machine is able to run of field easily and the efforts of the farmers are reduced. The operating, adjusting and maintaining principle of the developed reaper is made simple for effective usage by unskilled farmers.

Key words: Reaper, BBM, Concept selection, Design, 3D and 2D model by CATIA V5R17 software.

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Harvesting, an important field operation for any food grain crops, is the cutting process carried out when the crop attains physiological maturity such that a maximum recovery of quality product is obtained. Harvesting a crop at an appropriate stage of maturity minimizes the field losses, thereby, increasing the total yield as well as head yield. Consequently, to draw maximum benefit from the crop, harvesting must be done at the right time. (Amalendu et al., 2003)

Crops are harvested after normal maturity with the objective to take out grain, straw, tubers etc. without much loss. It involves cutting, picking, laying, gathering, curing, transport and stacking of the crops. In case of cereals like wheat and paddy the plants are straight and smooth and it contains grains at the top where as the most of oil seeds and pulse crops have branches which create problems in harvesting by manual or mechanical means. Timeliness of harvest is of prime importance. During harvesting season, often rains and storms occur causing considerable damage to standing crops. Rapid harvest facilitates extra days for land preparation and earlier planting of the next crop. The use of machines can help to harvest at proper stage of crop maturity and reduce drudgery and operation time. Considering these, improved harvesting tools, equipment, combines are being accepted by the farmers. (Sharma and Mukesh, 2010)

Harvesting is the first and major for post harvest operation like separation, processing and storage of grains. Harvesting of cereal grains by machines is an important part of mechanized agriculture. At present, developed countries all over the world are using automatic combine harvester for harvesting cereal grains. Some developing countries of south and Southeast Asia are also using combine harvesters for harvesting rice and wheat as a high grade technology. As a medium grade technology, many developing countries are using reaper for harvesting rice and wheat to minimize production cost, and are thereby, making agricultural production economical. Harvesting operation has to be done at a particular period but in shorter time. But, these two conditions cannot be fulfilled due to the shortage of manpower at that particular time. Therefore, a huge amount of grain loss is occurred for the lack of mechanized harvesting.

The methods and equipment used for harvesting depend upon the type of grain crop, planting method, and climate. The major grain crops are rice, wheat, corn, soybeans, barley, oats, sorghum, and dry beans. Crop harvesting was done by hand using sickles or scythes. The cut crop was bundled and carried to a central location where it was threshed either by beating it with a stick or by having hooved animals walk on it. (Ajit et al., 2012)

Most of the cereal crops are generally reaped by sickle which is quite tedious and labour intensive job. During the peak season of harvesting, Ethiopian farmers have to face the difficulty of getting their crop timely reaped due to shortage of agricultural laborers. Mechanical harvesting could be the answer to overcome this problem. (CSA, 2013)

Reapers are used for harvesting of crops mostly at ground level. As the population increases day by day, there is an increment of food. So, need of farm mechanization also increases. Machineries provide more operations in less time, but the machineries are very costly for the common man, it is not affordable for them. Therefore, manually operated machineries, equipment's are also the most important factor. Reaper harvesters on the other hand are other alternative harvesting equipment, provided straw is considered as economic by product for animal feed and industrial applications. Manually operated reaper is more important for it, this type of reaper can easily be operated by single person, and only the pushing efforts are required in less economy, easily affordable for farmers for keeping the better farming. (Chavan et al., 2015)

Harvesting using traditional method is time consuming, needs labour force, result grain loss etc. and also importing combine harvester machine increases foreign currency, will be too expensive and isn't affordable to our country farmers and investors. Therefore, it is important to recommend that it is very important to design and manufacture harvester and distribute to rural farmers and investors with minimum cost and light weight. (Abdurhaman et al., 2015)

Small scale farmers frequently face the problem of labour shortage or are unable to afford the wages to be paid. These problems prevent the fiscal growth of farmers and ultimately hamper the development of their farmland and family. Efficient, effective, cheap and productive techniques are needed to strengthen the farming community. (Aravind et al., 2015)

1.2. Statement of the problem

Harvesting requires a high labor input and the most tiring activity of crop production; the labor wage rate is often substantially higher than for other activities. Consequently, harvesting is a major expense in crop production. Moreover, in areas having labor shortages during the peak harvest period, delay harvesting from the optimum date reduces grain yield and quality. Harvesting using traditional method is time consuming, needs huge labour force, result grain loss, quality etc. Importing combine harvester is expensive and isn't affordable to small scale farmers. Farmers also need to recover both grains as well as the straw from wheat crops; because they need straw for their cattle's feed.

Now a day's farmers are sowing wheat crops in a row of BBF, a furrow prepared by BBM. It is practiced widely in vertisol areas to increase crop productivity. In Ethiopia, 12.7 million ha of land is covered by vertisol (CSA, 2015). These areas are important for cereal crop production. It is obvious harvesting is a critical issue and is an important step affecting the output of agricultural goods directly. Therefore, it is important to design and develop harvesting machine which is economical and suitable for local farmers. So, wheat crop reaper which it's operating, adjusting and maintaining principle are simple for handling by unskilled operators is to be made.

1.3. Objective of the study

❖ General objectives

The general objectives of this study is to

- Design and development of a device which is used to harvest wheat crops from furrows prepared with contemporary Broad Bed Maker.

❖ Specific objectives

- Studying about wheat crop properties and BBM technology
- Design and selection of parts of wheat crop Reaper such as main frame assembly, Belts, pulleys and shafts and cutting unit and conveying unit mechanisms
- Identify power source and means of drive

1.4. Methodology

❖ Literature collection

Literature collection is the process to get the information which is necessary to proceed the work. It includes reading books, journals and other resources related to the topic. Therefore,

- Identification of the type, advantage and history of reapers which is used to study their properties.
- Study the wheat crops physical properties and about BBM technology which is used to get necessary information for the design and analysis of wheat crop reaper.
- Study of cutting methods of cutting unit and general working principles of the reaper.

❖ Design and analysis

Design and analysis is the procedure used to calculate the dimension of every part, speed of movable part, maximum force applied on the part, bending effect, shearing and etc. The following are some of work that can come out:-

- Selection of material which can be obtained in the country
- Calculate the amount of the maximum force the material can stand up without fail
- Calculate the dimension of the part that will be designed
- Selection of standard material which can get from market like bearing, bolt and nut, etc.
- Identify the source of input power
- Selection of the best connecting mechanism
- Generating 2D and 3D of different components of the reaper by CATIAV5R17 software

1.5. Scope of the study

The study essentially covers the body design and analysis of manually driven and engine powered wheat crop reaper for furrows prepared by modern BBM. If the required fund is sponsored, the machine may be manufactured and put into practical in the future. For the thesis, it only addresses its detailed body design parameter calculations and analysis, generating 2D and 3D model with proper software's.

1.6. Significance of the study

This Study is to helpful for small land holding farmers to meet an increased demand for harvesting wheat grains, by designing the reaper to harvest grain crops more efficiently. This study will focusing on ease of harvesting operation to the small land holders farmers in the country for harvesting wheat crops in less time and at low cost. The operating, adjusting and maintaining principle are made simple for effective handling by unskilled farmers.

1.7. Limitation of the study

The prototype and actual manufacturing of the reaper was not done due to financial limitations. The thesis only addresses the design and analysis of the machine.

CHAPTER TWO

LITERATURE REVIEW

2.1. Historical perspectives

History indicates that reaping changes from a manual operation to a mechanized operation when the cost of labor increases to the point that machine use is more economical. (Binswanger, H. P., 1982)

Numerous efforts to develop a simple, low cost reaper appropriate for small farms in developing countries have not been particularly successful. However, a reaper developed in the people's republic of China may be a breakthrough and it has recently been modified by several institutions to adapt it to conditions in developing countries. (Bai Ling and Ma Ji., 1985)

After successfully testing the first prototype in the fall of 1981, Engineers decided to survey the demand for the reaper. Survey data were collected in early 1982 and the results published in 1983. Because of few imported combine harvesters and reaper binders were operating mostly on large farms, most farmers had never seen one. Therefore, surveyors described these machines to the farmers and got their reactions. (IRRI, 1986)

2.2. Mechanized farming

Mechanized agriculture is the process of using agricultural machinery to mechanize the work of agriculture, greatly increasing farm worker productivity. In modern times, powered machinery has replaced many jobs formerly carried out by manual labour or by working animals such as oxen, horses and mules. Mechanization involves the use of an intermediate device between the power source and the work. (Chavan et al., 2015)

Sustainable development in agriculture can be achieved by use of mechanization in agriculture. Mechanization can help in increasing the production by timely farm operation, reducing losses, reducing the cost of operations. It also ensures better management of costly inputs and enhances the productivity of natural resources. It also reduces drudgery in farm operations. Mechanization of different farm operations can increase the agricultural productivity by more work in less time,

efficient use of inputs, by producing quality product, improving the safety of the farmers and reducing the loss of produce. (Nilesh et al., 2013)

2.3. BBM technology

The BBM is a simple, locally manufactured plow used to make raised seed beds that enable excess water to drain from water logged soils. The design of the BBM, which is based on the traditional Ethiopian plow, has evolved into a relatively light implement with two mould board shaped wings attached to the traditional wooden frame. As a pair of oxen pulls the BBM through the soil, it makes two parallel furrows. The wings scoop the soil toward the middle, where it is then spread evenly by a chain attached at the back of the wings. This creates a raised seed bed, with furrows on either side that drain excess water. Still, the BBM is not a magic bullet that will make vertisols instantly more productive. Using the BBM enables farmers to plant and harvest earlier than their neighbors typically at least a month earlier. They are then able to sell their grain before others can get to market, and this usually means a higher price. Moreover, the early harvest may also allow for double cropping on the field, depending on what crops can be grown in the area. BBM demonstrations have also conclusively shown that the yields of improved wheat varieties grown on raised beds and using other recommended agronomic practices are far superior to those obtained from traditional flat furrow. (Triff, 2006)

The BBM was developed in the late 1980's from the traditional dual ox drawn plough, called as maresha by the joint vertisol project. In vertisol soils it is difficult to work, cracking occurs when dry and becoming sticky and water logged when wet. The role of BBM was to make raised seed beds and furrows more efficiently and effectively. (Nilesh et al., 2013)

The BBM was developed for Ethiopia in 1986. It is an ox drawn plough developed for Ethiopian conditions from a number of prototypes as a key component of a technology package designed to improve the productivity of vertisol soils in the highlands of Ethiopia. The BBM technology produces about 80 cm wide vertisol beds separated by 40cm for drainage, with bed approximately 25up to 30cm deep (<http://www.digitalgreen.org/>)

In Ethiopia, approximately 7.6 million ha (60%) of the estimated 12.7 million ha of vertisols are situated in the Ethiopian highlands. There is substantial evidence that adoption of the BBM technology can lead to improved productivity of vertisols and that there are opportunities to

increase this productivity further once farmers become more familiar with the technology. The BBM does save labour overall, especially for women and children and particularly in planting. However, these labour reductions from planting are largely offset by increased labour requirements in other activities, particularly land preparation and weeding.(Rutherford et al., 2001).

The Aybar BBM is the only known device capable of creating drainage furrows for excess water while building up a broad bed for planting. Up to 5 million hectares of land in Ethiopia and a much larger area in Africa are not available for farming because they are water logged. The Aybar BBM reveals this abandoned land, improving food production. Built on a 2,000 year old Ethiopian farming technology, it is easy to use and very cost effective. (Ethiopian News Paper (April-May), 2014)



Figure 2.1. BBM technology (source: www.aybareng.com)

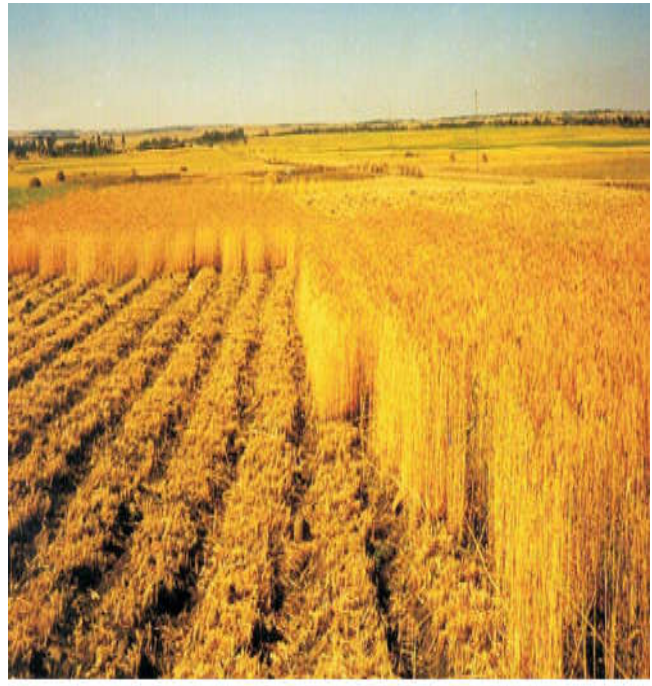
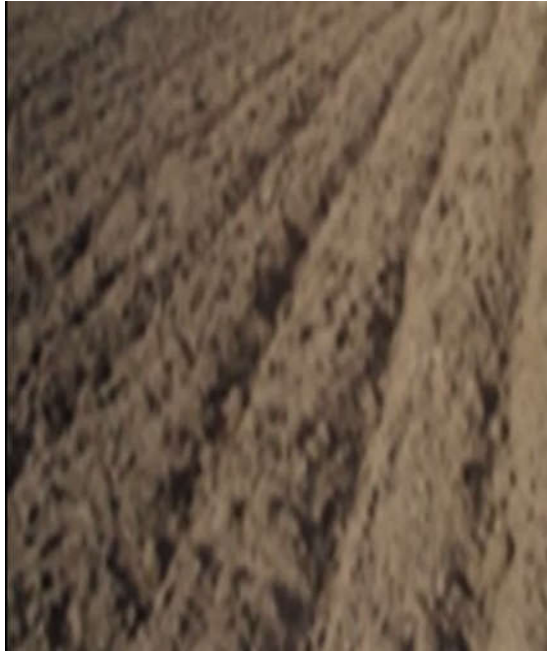


Figure 2.2. Furrows made by BBM (source: www.aybareng.com)

2.4. Grain crop harvesting

Once the grain has fully matured, it must be harvested. This involves cutting down the stalks of grain using a cutting mechanism and gathering them into bundles. Farmers have multiple harvesting practices depending on the size of their plot of land. A large farm harvests grain with either a large harvesting machine or a combine harvester. Harvesting by hand can be a slow and tedious process, but it remains the cheapest way for small scale growers. Once farms reach two or more acres in size however, hand tools become impractical, forcing farmers to utilize a range of mechanical harvesting equipment. (Christopher et al., 2012)

There are mainly four groups of technology available for harvesting of cereal crops. These technologies are: traditional using hand tools like sickle, intermediate technology using animal drawn harvesters, using reaper and modern technology by using combine harvester.

The simplest way is to use a hand sickle. This method is time consuming. The next development step is reaper, a machine which has a cutter bar of about a meter wide and it places the cut rice to the side in a neat row. Further up the scale of development is the self propelled harvester or combine harvester, a complex multifunction machine. This machine cut, thresh and clean the grain and fill in the bags for storage. The combine is very popular in developed countries. (Sharmin, 2014)

A sickle, or bagging hook, is a hand held agricultural tool designed with variously curved blades and typically used for harvesting, or reaping, grain crops or cutting succulent forage chiefly for feeding livestock, either freshly cut or dried as hay. Since the beginning of the iron age hundreds of region specific variants of the sickle have evolved, initially of iron and later steel. This great diversity of sickle types across many cultures can be divided into smooth or serrated blades, both of which can be used for cutting either green grass or mature cereals using slightly different techniques. The serrated blade that originated in prehistoric sickles still dominates in the reaping of grain and is even found in modern grain harvesting machines and in some kitchen knives. (<https://en.wikipedia.org/wiki/Sickle>)



Figure 2.3. Traditional way harvesting of wheat manually with sickle and combiner.

2.5. Reapers

Reaper is generally selected based on the land holding of the farmer, greater the land holding, tractor operated vertical conveyer reaper is choose, for medium land holding power tiller mounted vertical conveyer reapers are preferred. There are some different parameters which decide the selection and performance of reaper; they are as follows. Should have the proper cutting speed of cutter bar, require proper crop spacing, require proper power, continuous power transmission, proper registration and alignment of cutter bar and should require less effort. (Chavan et al., 2015)

According to the study reported, the use of a large scale machine is inappropriate due to the following reasons. It needs high technical experience for operation and maintenance, high capital requirements and low field efficiency is in small holding and losses of straw are high on irregular furrowed soils. The use of small machines is appropriate for small holdings, low capital requirements and low technical operations and maintenance experience. (Sahar, 1988)

According to (Shalini et al., 2015) the power required to drive the compact harvesting machine must be such that: It must carry variable load during constant running of machine., according to studies done on soybean crops the reciprocating speed should be 0.8 to 1.2 m/s, scissoring action is used to cut the crop, speed given to collecting mechanism will be more than the reciprocating mechanism and along with crop strength, strength of miscellaneous items such as weeds stems etc. also affects the power requirement.

Therefore, keeping these objectives in mind, the power required to drive the load is according to the power requirement of machine. It is stated the diesel engine with 3hp to 5hp may be required. So, being on the safer side diesel engine producing power of 2.7 kW (3.67hp) and 4000rpm is selected which is available currently in the market. The engine with this specification is also available in Melkassa Agricultural Research Center.

2.5.1. Cutting principle of cutter bar assembly

Reciprocating cutter blade slides over fixed blade and creates scissoring action responsible for cutting the crops. Collecting mechanism consists of flat belt. The cut crop is moved to one side

of the machine by the conveyor belt fitted with lugs and is dropped in the field. (Shalini P. et al., 2015).

For cutting biological materials, operation of a sharp or serrated edged knife is employed. It causes failure, primarily in shear. Shear failure is achieved either by using a single cutting element, such as a sickle, scythe, rotary cutters, or flail type cutters or by employing double cutting elements, as in scissors or reciprocating type cutters. Single element cutters, either moving with high velocity, linear or rotary motion, or stationary relative to the machine, are enough when the material being cut is thick and relatively strong in bending, or is supported over a fixed surface such as wood or ground to act as one of the other shearing elements. In this case, the crop material is supported well with the ground and is strong in bending, similar to sugarcane, pigeon pea or maize and the material would be able to resist the cutting force exerted by operation of a single cutting element. In all cutting processes, failure in shear or impact or both is possible when a system of forces acts on the material. (Amalendu et al., 2003)

The percentage of wheat and rice grain losses increasing as the machine forward speed increased. Increasing cutter bar speed leads to decrease the percentage of grain losses. Also, increasing forward speed leads to increase the number of uncut stalks. (Hadidi et al., 1984)

In cutting crop stems of cereal and pulses that are weak in bending, single element cutters moving at high velocity (linear or rotary motion) will require a low cutting force for close operation (minimum stubble height) of the cutting element. On the contrary, in the cutting of a group of stalks at an increased stubble height, greater cutting force will be experienced. Most cereal and pulse crops are harvested at ground level using two sharp shearing elements that meet and pass each other with little or no clearance. For failure in shear, either or both the elements may be moving and the motion may be linear with uniform velocity as in scissors, reciprocating or oscillating shear bar type, or rotary as in rotary cutters. (Amalendu et al., 2003)

Study done by (Habib et al., 2002) states that the parameters affecting cutting process are related to the cutting tool, machine specifications and plant materials properties. They added that, the cutting energy consumed in harvesting process.

2.5.2. Working principle of Reaper

According to (Laukik et al., 2014) walking behind type of harvester which is powered by human and the diesel engine is designed and fabricated. With the help of v-belt, drive power is transmitted to gearbox. As the required rpm at cutter is as less as 200rpm, a spur gearbox and a bevel gearbox will be used. Here bevel gear is used to change the direction of drive in the gear system by 90°. One end of this output shaft will be connected to slider crank mechanism which converts rotary motion of shaft into reciprocating motion of cutter blade.

The study done by (El-Sahrigi et al., 1992) on a front mounted reaper. The design features included a flat belt mechanism conveying the crop to the side of machine, improve cutter bar star wheel assembly to minimize clogging, a bevel gear drive for power transmission, a robust frame, a header provide design that will not dig in to the soil and provision to covert the flat belt conveyor drivers to chain without frame modification.

Study done by (Badr, 2005) comparing the performance of three different combines in terms of harvesting time, grain losses, fuel consumption, energy required and total cost. It is found that the highest field capacity of 3.02 acre/h and the lowest field efficiency of 70.5 percent were obtained at forward speed about 4.0 km/h and grain moisture content of 22%.

The team (Muhammad et al., 2015) has studied about grain losses of wheat as affected by different harvesting and threshing techniques and gives important economic analysis and interpretations. Wheat grain losses by different methods of harvesting and threshing are the following. Manual plus thresher, reaper plus thresher and combine harvester were evaluated by measuring different losses during harvesting and threshing processes of selected field. Major grain losses of wheat which were measured during the study are discussed as under: Pre-harvest losses, harvesting losses, threshing losses, harvesting and threshing losses, and quality losses and cleaning efficiency. The data revealed that manual harvesting and threshing techniques had considerable impact on grain losses of wheat than others.



+

Figure 2.4. Reapers: tractor mounted and manual driven

2.6. Wheat crops

Wheat is one of the major staple and strategic food security crops in Ethiopia. It is cultivated on 1,627,647.16 ha of land and has the production of 34,347,061.22 quintals with productivity of 21.10 kg/ha in Ethiopia. (CSA, 2013).

Strength of wheat and barley stems is investigated to determine the static loads of wheat and barleys, spike weights are measured. The average weight of spikes for wheat is 1.45g and for barley it is 3.57g. Average outer diameter of wheat and barley corresponding to different heights from the ground are given in Figure 2.5. The average outer diameter increases some amount with the height and then decreases. Under the effect of aero dynamical forces to the spike, the bending moment is maximum in the region close to the root. It should be expected that the outer diameter be maximum close to the root. The tensile tests are conducted to determine the elasticity modulus of the specimens. An average value of 6799MPa is found for wheat stems and 11064MPa for barley stems. (Gozde et al., 2010)

2.7. Engineering design process

Machine design is the creation of new and better machines and improving the existing ones. A new or better machine is one which is more economical in the overall cost of production and operation. The process of design is a long and time consuming one. From the study of existing ideas, a new idea has to be conceived. The idea is then studied keeping in mind its commercial success and given shape and form in the form of drawings. In the preparation of these drawings, care must be taken of the availability of resources in money, in men and in materials required for the successful completion of the new idea into an actual reality. In designing a machine component, it is necessary to have a good knowledge of many subjects such as mathematics, engineering mechanic, strength of materials, and theory of machines, workshop processes and engineering drawing. (Khurmi and Gupta, 2005).

In early stages of design process the designer uses his ingenuity and imaginative thinking power for definition and understanding the design problems as shown in figure below. To design is either to formulate a plan for the satisfaction of a specified need or to solve a problem. If the plan results in the creation of something having a physical reality, then the product must be functional, safe, reliable, competitive, usable, manufacturable and marketable. Design is an innovative and highly iterative process. It is also a decision making process. Decisions sometimes have to be made with too little information, occasionally with just the right amount of information, or with an excess of partially contradictory information. Decisions are sometimes made tentatively, with the right reserved to adjust as more becomes known. The point is that the engineering designer has to be personally comfortable with a decision making, problem solving role. Design is a communication intensive activity in which both words and pictures are used, and written and oral forms are employed. Engineers have to communicate effectively and work with people of many disciplines. These are important skills and an engineer's success depends on them. A designer's personal resources of creativeness, communicative ability, and problem solving skill are intertwined with knowledge of technology and first principles. Engineering tools such as mathematics, statistics, computers, graphics and languages are combined to produce a plan that, when carried out, produces a product that is functional, safe, reliable, competitive, usable, manufacturable and marketable regardless of who builds it or who uses it. (Budynas et al., 2008)

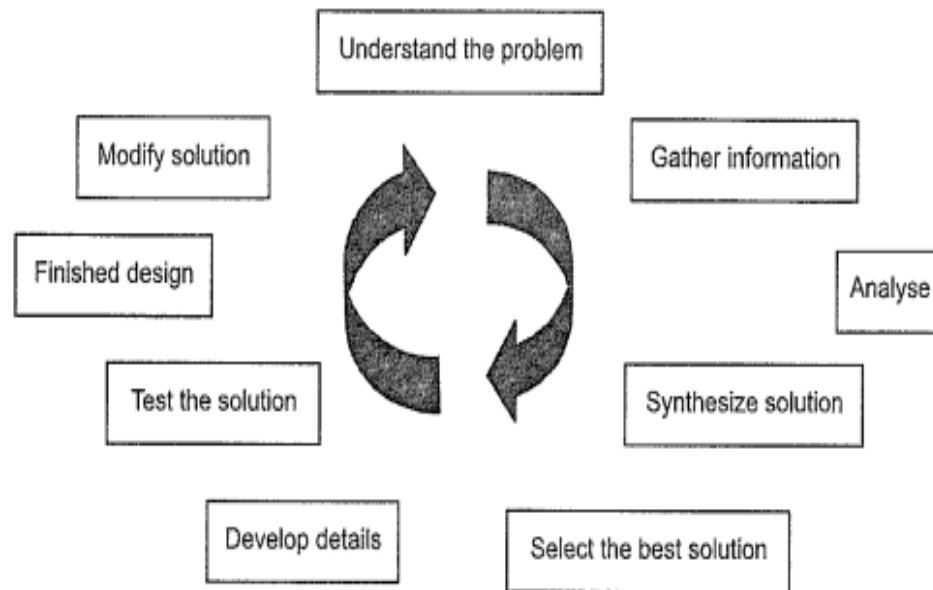


Figure 2.5. Engineering design process

Design generally begins with either a need or requirement or, alternatively, an idea. It ends with a set of drawings or computer representations and other information that enables a product to be manufactured and utilized. (Peter Childs, 2004)

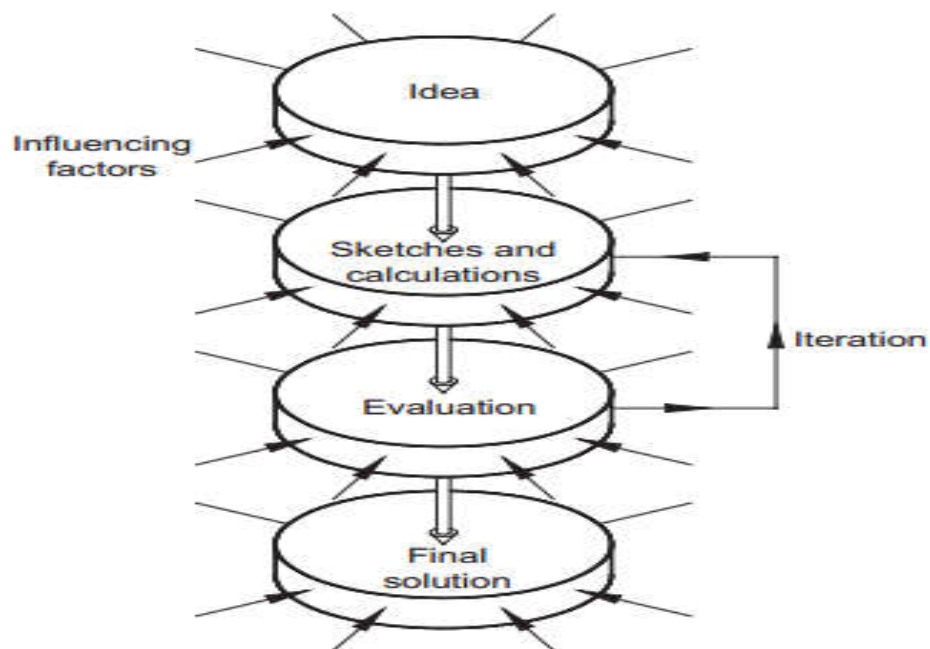


Figure 2.6. The traditional and familiar inventor's approach to design.

2.8. Land holding in Ethiopia

The relation of technology use and farm size was observed by categorizing farm holdings into three size groups: Small size farms, 0.50 ha and less; Medium size farms, 0.51 ha up to 2.0 ha, and; Large size farms, above 2.0 ha. Therefore, Small scale farmers are those who have a farm area less than 2ha. (Samuel, 2006)

The decreasing trend in operational land holding is also obstructing the growth of agricultural mechanization. High costs of machines and maintenance, non availability of appropriate agricultural machines and equipment that provide to and suit the requirements of small scale farms, non-availability and difficulty in getting bank credit and small land holding are some of the factors that hinder farm mechanization and force farmers to follow the traditional ways of agricultural operations. Ethiopia continues to be fed by its marginal and small farmers. In Ethiopia, agriculture accounts about 42% of the GDP, employs about 85% of the labor force and contributes around 90% of the total export earnings of the country. The sector is dominated by over 15 million small holders producing about 95% of the national agricultural production. This shows that the overall economy of the country and the food security of the majority of the population depend on small holder agriculture. The growth of agricultural sector is taken as an engine and the last option to impression the national economy. (CSA, 2015)

CHAPTER THREE

CONCEPT GENERATION AND SELECTION

3.1. Introduction to Concept generation and selection

Concept generation answers the question of how the product will satisfy the needs as mapped into the functional specifications. The concept generation stage of product development is where the skill, experience and creativity of design team are used to generate designs which address the identified needs of the clients and the users to create a factor. Ideas are like prototypes. They need to be tested to verify they fit client needs. Once concepts are generated, designer can present them in a variety of formats to enable full understanding and evaluation of the concepts. Concept generation is analyzed in two ways, implicitly through sketches and then explicitly through enumerated design alternatives. First, ideas are observed through sketches created by designers. Sketching is an integral part of the engineering design process and provides one form of evidence of design activity. Second, method examines concept generation more directly through the quantity of ideas created through brainstorming and in morphology charts. Brainstorming is free-form, unstructured concept generation activity. Morphology charts are hierarchies of alternative embodiments that can fulfill each of a device's functions. (Lemi, 2014)

The product considered in this work, is analyzed, evaluated, ranked and selected through design aspects such as design for manufacturing, ergonomics, economic, function and safety. product attribute function is obtained from product attribute matrix. Indices for different product alternatives are calculated through product attribute function and they are ranked in descending order. The product with higher total weight value is selected as best one in the view of design aspects.

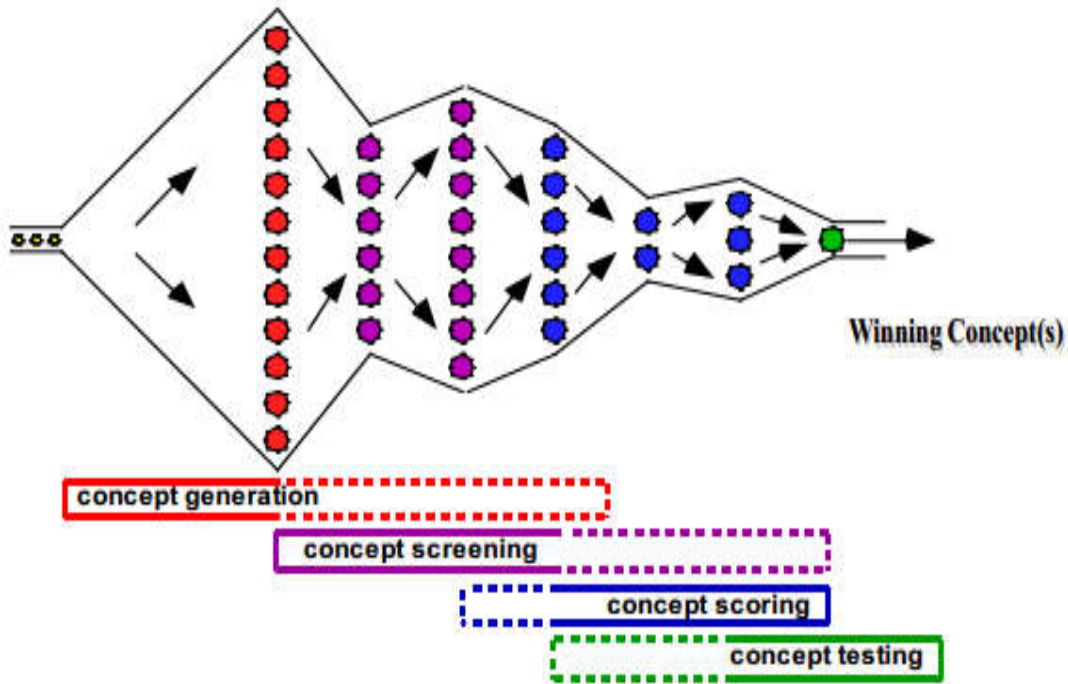


Figure 3.1 Concept developments funnel

General methodology for concept selection

- Concept screening:- this alone may suffice for simple design decisions. This is a quick, approximate evaluation aimed at producing a few viable alternatives. Rough initial concepts are evaluated relative to a common reference concept using the screening matrix.
- Concept scoring:- this is a more careful analysis of the relatively few concepts that make it through screening in order to choose the single concept most likely to lead to product accomplishment. This is more finely detailed with finer quantitative evaluation using the scoring matrix as a guide. concept scoring is used when increased resolution is better differentiate among competing concepts. In this stage the team weights the relative importance of the selection criteria and focuses on more refined comparisons with respect to each criterion.

The screening matrix and scoring matrix are each used by the team to rate, rank and select the best concepts. The team may well also apply their collective insight to improve and combine concepts.

Common steps for screening and scoring matrices

Prepare the selection matrix:- selection criteria and concepts are used to provide the basic rows and columns of the matrix. Concepts should be presented at similar levels of detail for meaningful comparison and unbiased selection.

Rate the concepts

For screening:- better than (+), same as (0), worse than (-) is placed in each cell of the matrix rating the concept in comparison to the reference concept relative to the specific criterion. Such measures help to minimize the judgmental nature of the rating process. Objective measures for concept selection may arise from target specifications. Rank orders the concepts with those concepts with more pluses and fewer minuses (for screening) are ranked higher and give high rank for the concept based on total score.

For scoring:- a finer scale is used with the following being recommended. Rating relative performance

1. Much worse than reference concept
2. Worse than reference concept.
3. Same as reference concept.
4. Better than reference concept.
5. Much better than reference concept

3.1. Functional interrelation

Functional interrelation is a method for analysing and developing a function structure. Function structure is an abstract model of the new product without materials features such as shape, dimensions and materials of part. Function tells what the product must do whereas its form or structure, conveys how the product will do it. Functional interrelation includes logical flow of energy, material and information between object. (Lemi, 2014)

Machine pulled or pushed by man power. The cut crops are conveyed to one side by the conveyors. Later this conveyed crop is gathered by man power. Due to the force applied on the machine move forward on the furrow by rotation of wheel. The effect of non uniformity of land surface on the harvester may be solved based on the height controlling. The cutting of crops is

due to reciprocating action of cutter blades attached on moveable cutter bar over fixed cutter bar. Power is transferred from engine to belts by rotation of pulley and then to shaft with the aid of gear box. Power is transferred to the next part. i.e. to reciprocating cutter bar. This reciprocating cutter bar motion is due slider crank mechanism principle which converts rotary motion to linear motion. Due to scissoring action of cutter blades on reciprocating cutter bar, wheat crop stems cut away from furrows prepared by BBM. The cut crop is conveyed to one side. This conveyed crop is collected manually by man power later on. The source of power for conveyor can be power transmitted from engine.

All procedures are summarized as following figure

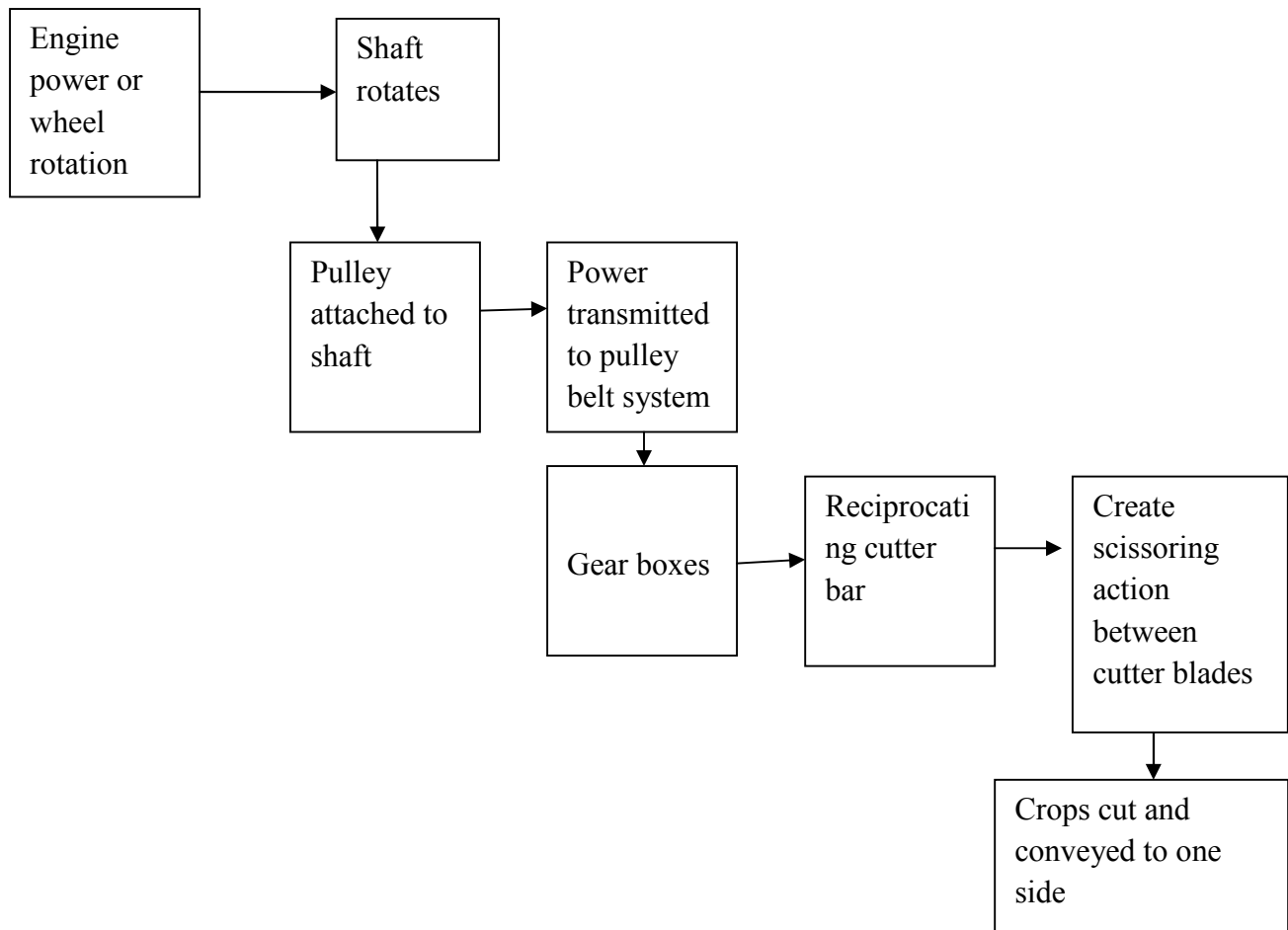


Figure 3.2. Functional interrelationship of wheat crop reaper

3.2. Task specification

Task specification is a collection of information about the requirements to be embodied in the solution and also about the constraints.

Note that D means demand and W means wish

Demands are requirement that must be met under all circumstances but wishes are requirements that should be taken into consideration whenever possible. The distinction between demand and wishes is also important at the evaluation stage.

Table 3.1. Task specifications

D or W	Requirements
	Geometry
D	Height of cutter bar from ground level is up to 100 mm
W	Distance between the wheel is up to 400 mm
D	Length of cutter bar 800 mm
W	Distance between engine and spur gear box is up to 400 mm
D	Height of handle from ground up to 1000 mm
W	Distance between spur gear and bevel gear box is up to 400 mm
D	Slider crank mechanism convert rotary motion into linear
	Kinematics
D	wheel rotate in forward direction on an axle
D	Pulley rotate in any desired direction
W	pulley of conveyor rotate in clockwise direction
D	The machine move forward with speed of average walking speed. i.e 0.8m/s
W	Cut crop move in uniform amount and speed
	Force
D	Enough friction force between wheel and land which resist slip must be available.
D	Rpm of engine has to be reduced at cutter bar
	Material
W	Low cost and locally available is to be selected
W	Materials to be used has to be fabricated locally

3.3. Establishing functional structure

The functional basis uses function and flow words to form a sub function description as a function and a flow (i.e. a verb object format). Generation of a black box model, creation of function chains for each input flow, and aggregation of function chains into a functional model are the sequence of steps that lead to the repeatable formation of a functional model in their approach. The black box model is constructed based on the overall product

function and includes the various energy, material, and signal flows involved in the global functioning of the product. The detailed functional model is then derived from sub functions that operate on the flows listed in the black box model.(Lemi , 2014)

3.3.1. Overall function

Overall function describes the general relation between input and output. All functional process between input and output represent by black box. The black box contains all the functions which are necessary for converting the inputs into the outputs

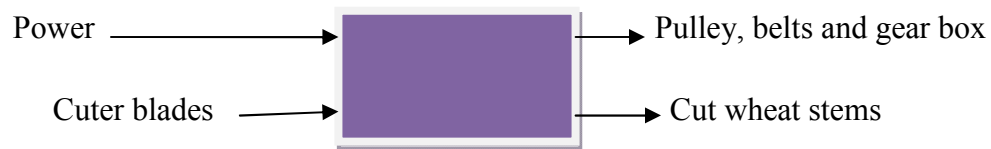


Figure 3.3. Over all function

3.3.2. Decomposition of overall function

Just as a technical system can be divided into subsystems and elements, so a complex or overall function can be broken down in to subfunctions of lower complexity. The combination of individual subfunctions results in a function structure representing the overall function.

The aims of breaking down complex functions are to

- Determine subfunctions that facilitate the subsequent search for solutions
- Combine these subfunctions into a simple and unambiguous function structure.

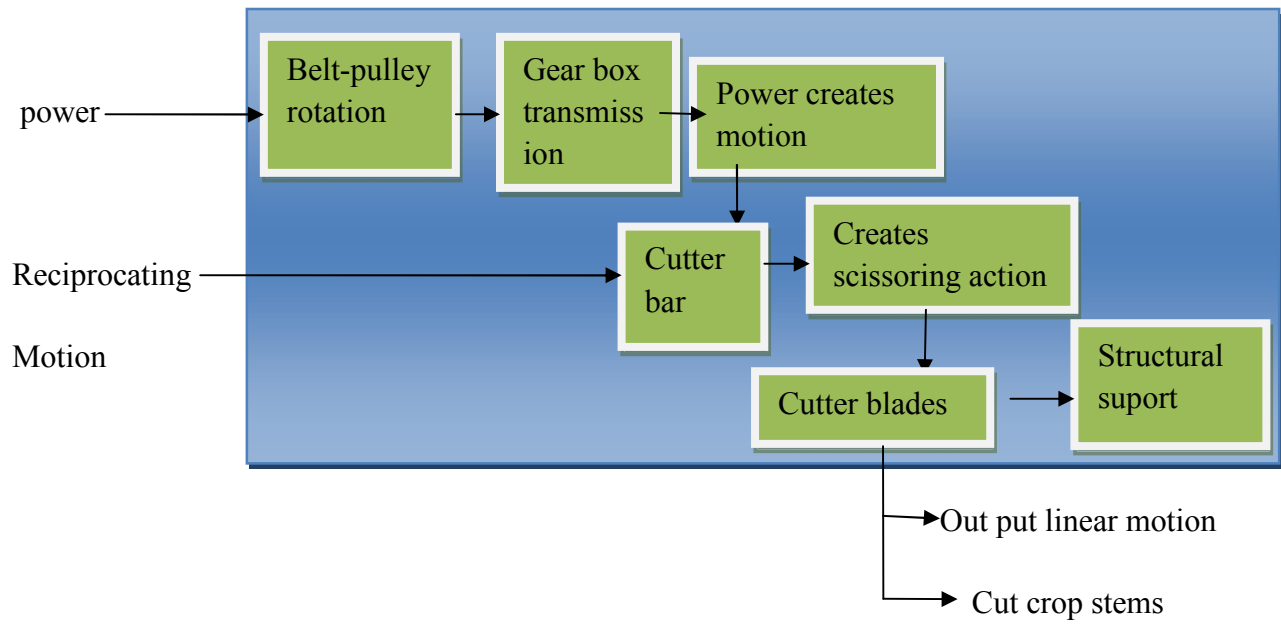


Figure 3.4. Over all functions decomposition

3.4. Possible solution for sub-function

Possible solution is used to select best option for every sub function which come together and fulfill over all function.

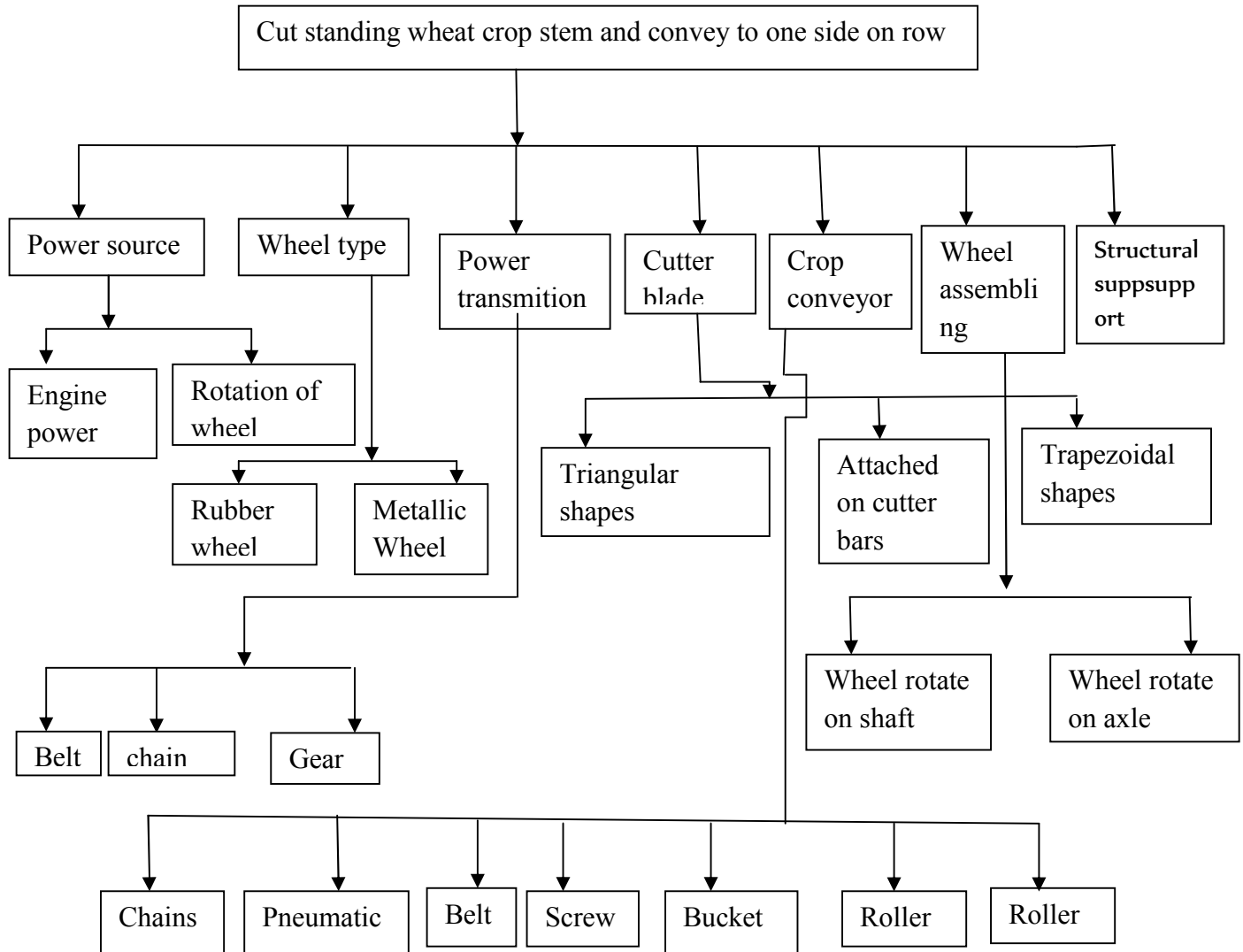


Figure 3.5. Alternative tree for sub-function

3.5. Analyzing and evaluating the product alternatives

Selection of power source

Power used to operate the machine may be obtained from engine or rotation of wheel. During the pushing and pulling the machine wheel rotates. From this rotation power to cut crop may be gained. When engines run to cut crops, pushing and pulling the machine may be employed by man power. The following procedure takes place for selection.

List selection criteria

- efficiency:- evaluation of the way it fullfill the objectives without material loss.
- flexibilty:- ability it can attatched to many kind of power source
- Easy for Cutting and Conveying
- Manufacturable
- Cost

Table 3.2. Attribute matrix of power option

Criteria	Weight	Concept			
		Engine Power		Rotary motion of wheel	
		Rate	Weight score	Rate	Weight score
Efficiency	30	3	0.9	1	0.3
Flexibility	25	3	0.75	2	0.5
Easy for cutting and conveying	20	3	0.6	1	0.2
Manufacturable	10	3	0.3	4	0.4
Cost	15	3	0.45	4	0.6
Total sum	100		3.0		2
Rank		1		2	

Selection of wheel

The ground of the crops may not fully flat surface or irregularity of the land flatness may take place. Height of furrow is high during its wet season. The height shrinks down when the soil is dried. There may be some ridge and stone. This may cause us to increase the height of the wheel. There are two types of wheel used for the machine harvester. These are metal type and rubber wheel. To select the best from the given alternatives, selection criteria are given as follow.

Selection criteria:

- a. Durability
- b. Structural complexity
- c. Amount of height change
- d. Space compactability
- e. Simplicity of manufacturing
- f. cost

Table 3. 3: Attribute matrix for wheel type

Criteria	Weight	Concept			
		Metal Wheel		Rubber wheel	
		Rate	Weight score	Rate	Weight score
Durability	25	3	0.75	2	0.5
Structural complexity	20	3	0.6	2	0.5
Simplity of manufacturing	18	3	0.54	1	0.18
Amount of height change	12	3	0.36	3	0.36
Structural complexity	10	3	0.3	2	0.2
Cost	15	3	0.45	2	0.3
Sum total			3.0		2.04
Rank		1		2	

Wheel assemblage to Main frame

Based on the way it can be assembled on the main frame, there are two options. The first case is make tire wheel rotate on shaft. The second case may the wheel rotate on an axle.

Selection criteria

- a. Complexity
- b. Cost
- c. Manufacturing
- d. Maintenance
- e. Availabilty on market

Table 3. 4. Attribute matrix for wheel assembling

Criteria	Concept				
	Weight	wheel rotating on shaft		wheel rotate on axle	
		Rate	Weight score	Rate	Weight score
Complexity	35	3	1.05	5	1.75
Cost	25	3	0.75	4	1
Manufacturing	15	3	0.45	4	0.6
Maintenance	15	3	0.45	2	0.3
Availability in the market	10	3	0.3	3	0.3
Total sum			3.0		3.95
Rank	2			1	

Power transmission

Motion and power are transmitted from one machine to another. The most common are the rotary motion drives; this is attributable to the substantial advantages of uniform rotary motion over reciprocating motion. power is transmitted by gear, belt, shaft, rope, and etc. power is transmitted from engine to reciprocating cutter bar through belt pulley arrangement. The choice of a

transmission depends upon the intended use of and requirements for a given drive. It is generally required that the transmission should selection criteria.

1. Have adequate reliability
2. Service life.
3. Be simple in construction.
4. Have adequate compactness and be small in size.
5. Offer a little resistance to motion, especially when the prime mover is start
6. Exhibit adequate accuracy of motion transformation (kinematics accuracy)
7. Produce little noise in service.
8. Offer substantial resistance to vibration.
9. Be easy to control.

Table 3.5. Attribute matrix for power transmission

Criteria	Weight	Concept					
		Belt		Chain		Gear	
		Rate	Weight score	Rate	Weight score	Rate	Weight score
1	10	3	0.3	4	0.4	3	0.3
2	15	3	0.45	4	0.6	4	0.6
3	20	3	0.6	1	0.2	2	0.4
4	12	3	0.36	2	0.24	3	0.36
5	10	3	0.3	4	0.4	3	0.3
6	8	3	0.24	4	0.32	3	0.24
7	6	3	0.18	1	0.06	3	0.18
8	4	3	0.12	1	0.04	2	0.08
9	15	3	0.45	2	0.3	3	0.45
Sum total			3.0		2.56		2.91
Rank			1		3		2

Cutter blades shapes

Cutter bar assembly consists of a sliding cutter plate and a stationery cutter plate. It is a metallic rectangular bar, on which triangular or trapezoidal blade sections are mounted. The knife cuts the wheat crop stem by its reciprocating action. The knife sections make reciprocating motion and cuts the plants. Cutter blade is used to cut the wheat crops from at ground level. The number of blades and its shape may effects amount loss of material.to have effective cutting the blade has to be serrated and cut the crop without failure. Two option for shape of blades, triangular and trapezoidal shapes.

Selection criteria:

- a. Manufacturing simplicity
- b. Advantage of crop dividing
- c. Durability
- d. Suitablity with height of standing crops
- e. Resistance of impact force
- f. Assembling simplicity
- g. Cost

Table 3. 6. Attribute matrix for cutter blade shape

Criteria	Weight	Concept			
		Triangular		Trapezoidal	
		Rate	Weight score	Rate	Weight score
Manufacturing simplicity	12	3	0.36	2	0.24
Advantage of crop dividing	25	3	0.75	4	1
Durability	20	3	0.6	2	0.4
Suitability with height of standing crops	15	3	0.45	2	0.3
Resistance of impact force	12	3	0.36	4	0.48
Assembling simplicity	10	3	0.3	2	0.2
Cost	6	3	0.18	2	0.12
Total sum			3		2.74
Rank			1		2

Cut crop conveyors

These are powered equipment commonly used for moving bulk or unit load continuously. The primary function is conveying of the cut crop by the help of movement of some parts or components of the equipment. The cut crop has to convey to one side. The conveyor of the machine must convey the bunch of the cut crop continuously and without blockage.

The major sub classifications and some of the common individual equipment under these sub classifications are mentioned in the following lists:

- a. Belt conveyor:- flat belt, trough belt, closed belt, metallic belt, portable belt, telescoping belt
- b. Haulage conveyor:- a special class of chain conveyor in which load is pushed or pulled and weight is carried by stationary troughs, surface or rail. It include drag chain,flight meta,tow.

- c. Chain conveyor:- apron or pan, slat, cross bar or arm, car type or pallet, enmass, carrier chain and flat top, trolley, power and free, suspended tray or swing tray
- d. Cable conveyor
- e. Bucket conveyor:- gravity discharge, pivoted bucket, bucket elevator
- f. Roller conveyor:- gravity, powered or driven, portable
- g. Screw conveyor
- h. Pneumatic conveyor
- i. Hydraulic conveyor

Selection criteria

- A. Effectiveness for material to be conveyed.
- B. Conditional effect like moisture
- C. Flexibility
- D. From what is being moved
- E. To what the product moved
- F. How far will it travel horizontally
- G. At what rate is the material being moved
- H. For how long will the conveyor operate each day
- I. Will the conveyor operate in a hot or cold area
- J. Will the conveyor be readily accessible for maintenance
- K. How long is the conveyor expected to run between services
- L. Energy consumption
- M. Cost
- N. Construction simplicity

Step one :Concept screening

Table 3.7. Attribute matrix for concept screening of conveyor selection

Criteria	Concept						
	Pneumatic	Chain	Bucket	Rope	Roller	Screw	belt
A	0	0	-	+	-	-	0
B	0	0	+	-	0	-	0
C	0	-	-	+	-	-	0
D	0	0	+	+	-	+	0
E	0	0	0	0	-	0	0
F	0	0	+	+	-	+	0
G	0	-	-	-	-	-	0
H	0	+	+	+	+	+	0
I	0	-	-	-	-	+	+
J	0	-	-	-	+	-	+
K	0	-	-	+	-	-	+
L	0	0	0	-	+	0	+
M	0	-	-	-	+	-	+
N	0	-	0	-	-	+	+
Sum of +'s	0	2	4	6	4	5	6
Sum of -'s	0	6	7	8	9	7	0
Sum of 0's	14	6	3	1	1	2	8
Net score	0	-4	-3	-3	-5	-2	6
Rank	2	6	4	5	7	3	1
Continue?	Yes	No	Yes	Yes	No	Yes	Yes

Step two: Concept scoring

- A. Effectiveness for material to be conveyed.
- B. Flexibility
- C. From what is being moved
- D. To what the product moved
- E. How far will it travel horizontally
- F. At what rate is the material being moved
- G. Will the conveyor be readily accessible for maintenance
- H. How long is the conveyor expected to run between services
- I. Cost
- J. Construction simplicity

Table 3. 8. Attribute matrix for scoring of conveyor selection

Criteria	Weight	Concept									
		Bucket		Pneumatic		Lugged Belt		Rope		Screw	
		Rate	Weight score	Rate	Weight score	Rate	Weight score	Rate	Weight score	Rate	Weight score
A	17	3	0.51	1	0.17	5	0.85	3	0.51	2	0.34
B	5	3	0.15	4	0.2	2	0.1	3	0.15	2	0.1
C	15	3	0.45	4	0.6	4	0.6	3	0.45	1	0.15
D	6	3	0.18	4	0.24	3	0.18	3	0.18	1	0.06
E	10	3	0.3	5	0.5	5	0.5	3	0.3	3	0.3
F	8	3	0.24	1	0.24	2	0.16	4	0.32	2	0.16
G	9	3	0.27	2	0.18	2	0.18	4	0.36	2	0.18
H	5	3	0.15	4	0.2	5	0.25	4	0.2	5	0.25
I	12	3	0.36	2	0.24	2	0.24	3	0.36	2	0.24
J	13	3	0.39	2	0.26	2	0.26	2	0.26	2	0.26
Total sum			3.0		2.83		3.32		3.09		2.04
Rank			3		4		1		2		5

3.6. Aternative evaluation tree summary

After analysis alternative evaluation the best alternatives are selected. Figure below shows the first option selected altenatives.

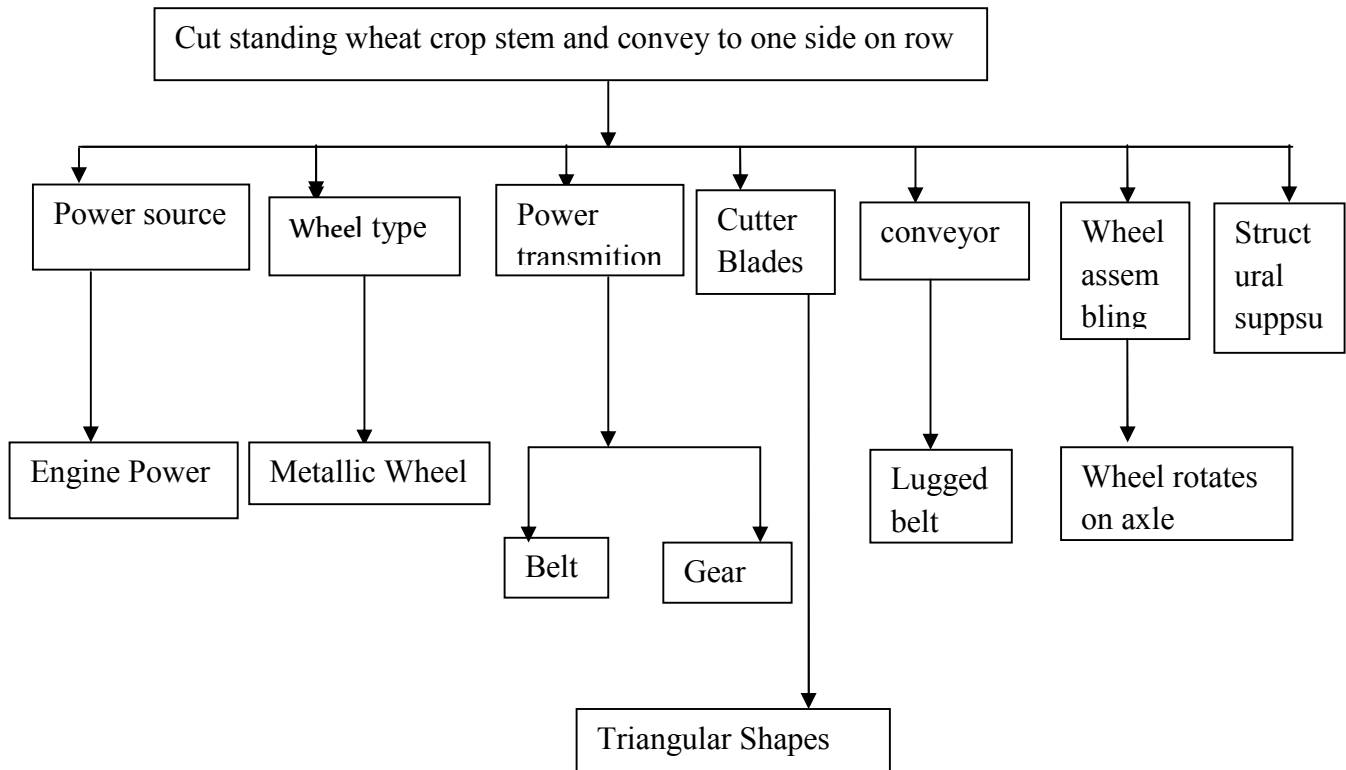


Figure 3. 6: Result from alternative tree evaluation

CHAPTER FOUR

EMBODIMENT DESIGN OF WHEAT CROP REAPER

4.1. Introduction to embodiment design and selection of material

It is a process of giving concrete form to an abstract concept. During the embodiment phase the designers must determine the overall layout design, general arrangement and spatial compatibility, the preliminary form designs or component shapes and materials and the production processes, and provide solutions for any auxiliary functions. During all of this, technological and economic considerations are of paramount importance. (Lemi, 2014)

The best material is one which serves the desired objective at the minimum cost. The following factors should be considered while selecting the material. Availability of the materials, suitability of the materials for the working conditions in service and the cost of the materials. (Khurmi and Gupta, 2005)

The reaper consists of main frame, diesel engine, belt drive, spur gear box, coupling, and cutter assembly, collecting belt, bevel gearbox and metallic drive wheels. The machine performs two operations harvesting and collecting. There are two cutter blades; one is moving and another is stationary on the main frame. The slider crank mechanism is used to convert rotary motion to linear motion in the cutter bar assembly.

4.2. Design of main frame assembly

The main frame, which is the frame work of the Reaper, supports all parts of the harvester. The main frame assembly of manual driven engine powered wheat crop Reaper has been selected on the basis of crop parameters and load requirements. The two design factors considered in the determination of the material required for the main frame were weight and strength. In this design, hollow mild steel section bar of 30 mm x 30 mm and 3 mm thickness was used to give the required strength and rigidity, so that it can withstand all types of load during operation.

The wheel base is selected considering the row to row spacing of wheat crops and number of rows harvested. Row to row spacing for wheat is 20 cm for normal furrows. But, for furrows prepared by BBM covers about 80 cm in width. That means it may have up to 4 row spacing of wheat. The frame of the harvester with the dimension $800 \times 400 \times 500$ (l $\times$ b $\times$ h) mm³ is designed. The frame is light and strong enough to sustain weight of diesel engine and all other attachments. After frame is developed it was time for engine mounting. Connections between the frame and other component parts of the reaper were made using appropriate sizes of bolts, nuts and welding together properly.

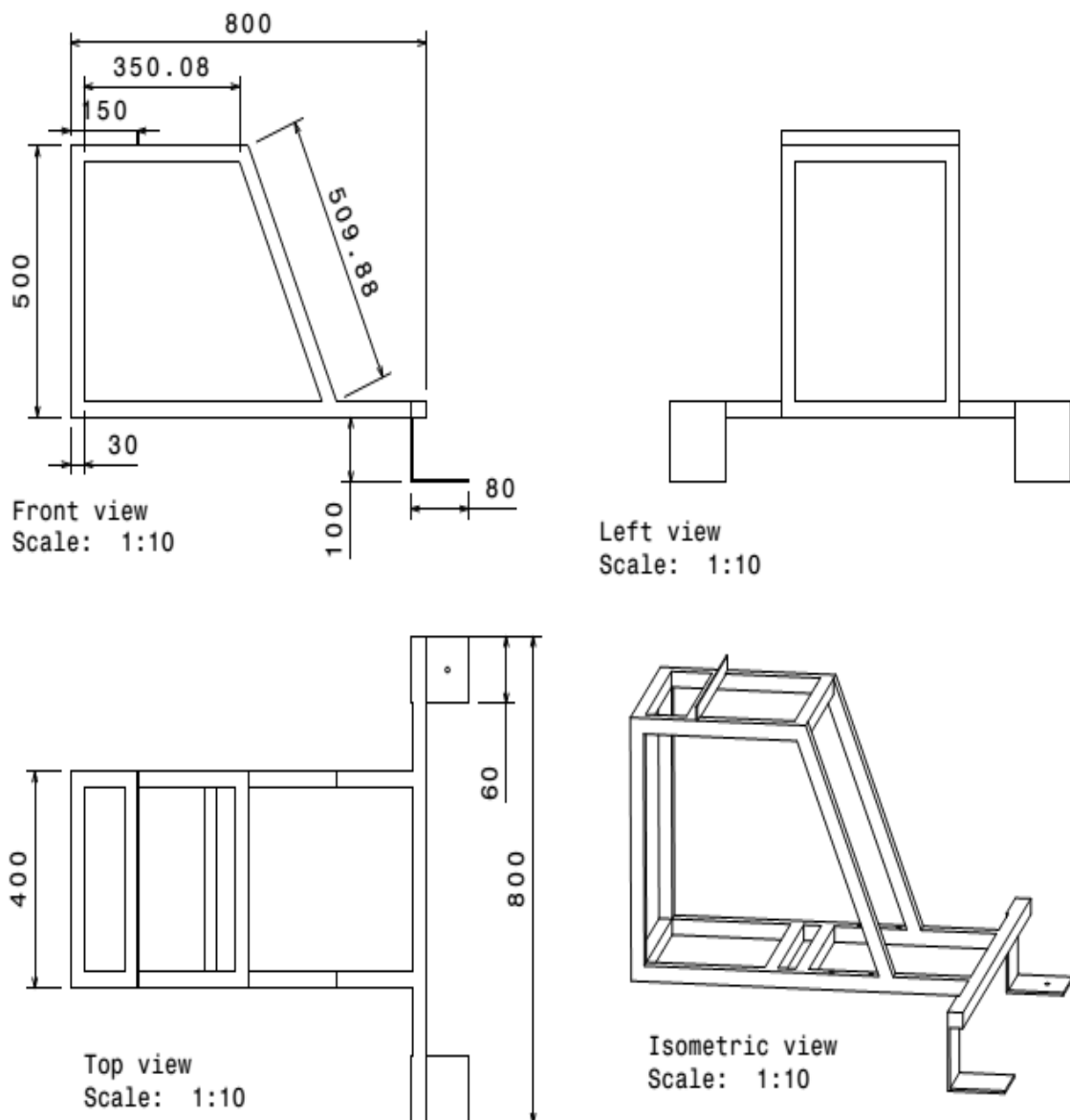


Figure 4.1. Main frame assembly

4.3. Estimation of force required to push the Reaper

According to (Sharma and Mukesh, 2010) the power of useful work done by human being is given by:

$$P = 0.35 - 0.092 \log t \dots\dots\dots (4.1)$$

Where, P = power in horse power

t = time in minute

For four hours continuous work, power developed by a man is $P = 0.35 - 0.092 \log(4 \times 60)$

$$P = 0.131 \text{ hp}$$

It is known that,

$$P = \frac{\text{push} \times \text{speed}}{75} \dots\dots\dots (4.2)$$

Let speed of operating the machine be $= 0.8 \frac{\text{m}}{\text{s}}$. Therefore, from equation (4.2)

$$\text{push} = \frac{75 \times 0.0964 \text{ kW}}{0.8 \text{ m/s}} = 9.038 \text{ KN}$$

$$\text{hp} = \frac{2\pi \times N_g \times T_g}{4500} \dots\dots\dots (4.3)$$

N_g = rpm of ground wheel

T_g = torque developed by the ground wheel

$$V = \frac{\pi \times D \times N_g}{60} \dots\dots\dots (4.4)$$

V = Operating speed of reaper, take 0.8 m/s

D = Diameter of ground wheel,

It is taken, D = 0.4 m putting these values in equation (4.4),

$$N_g = \frac{v \times 60}{\pi \times D} = \frac{0.8 \text{ m/s} \times 60}{\pi \times 0.4 \text{ m}} = 38.217 \text{ rpm}$$

Putting this value in equation (4.3)

$$T_g = \frac{H_p \times 4500}{2\pi \times N_g} = \frac{0.0964 \text{ kW} \times 4500}{2\pi \times 38.217 \text{ rpm}} = 1.807 \text{ kNm. } T_g = 1.807 \text{ kNm}$$

4.4. Determination of forces acting on the cutter bar of Reaper

The total resisting force (F) acting on the cutter bar is the sum of all the forces acting on the knife. (Sharma and Mukesh, 2010)

$$F = F_c + F_f + F_i \quad \dots\dots\dots (4.5)$$

Where F= total resisting force on cutter bar, N or Kg

F_c = average resistance to cutting, N or Kg

F_f = frictional force N or kg

F_i = inertia force of knife section, N or Kg

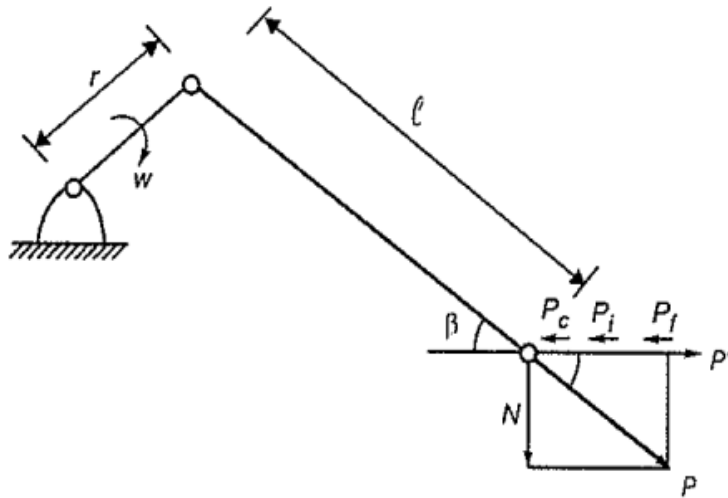


Figure 4.2. Forces acting on cutter bar of Reaper

4.4.1. Cutting force in the cutter bar

To estimate resistance to cutting for cereal crops, it is assumed that the plants are uniformly distributed in rows and wheat crop on BBF will be cut by engine powered machine. The total cutting force (F_C) on the cutter bar is given by (Sharma and Mukesh, 2010)

$$F_C = \frac{E F_t Z}{X_c} \dots\dots\dots (4.6)$$

F_C = total cutting force in cutter bar, N

$E = 1.25 \text{ N-Cm/Cm}^2$ for wheat crop and $2.0 \frac{\text{N-cm}}{\text{cm}^2}$ (for paddy)

F_t = knife load area for single stroke cutter. It is calculated, 20.625 Cm^2

Z = Number of knife section in the cutter bar is 10 for 80 cm cutter bar

X_c = Displacement of knife, start to end of cutting = 3.75 cm for the designed knife section

Putting values in equation (4.6), $F_C = \frac{1.25 \frac{\text{Ncm}}{\text{cm}^2} \times 20.625 \text{ cm}^2 \times 10}{3.75 \text{ cm}} = 68.75 \text{ N}$

4.4.2. Inertia force in cutter bar

The inertia force acting on the cutter bar is governed by the mass (M_k) of reciprocating cutter bar, it is given by (Sharma and Mukesh, 2010)

$$F_i = M_k r \omega^2 \left(1 - \frac{x}{r}\right) \dots\dots\dots (4.7)$$

Where, M_k = mass of knife section, kg

r = radius of crank, cm

ω = angular velocity, rad/sec

x = length of stroke, cm

At initial and final points of stroke, F_i would be maximum. So, $F_{i \max} = M_k r \omega^2$

Determination of crank radius and stroke length of the cutter bar

Conventionally, all three types of reciprocating cutter-bar use a plane, asymmetric crank system in mowers, reaper windrowers, and combine harvesters for which the axis of rotation of the crank is perpendicular to the plane of oscillation. Such cutter bars are required to be operated at

some prefixed level; therefore, the crank center is located at a height m above the cutter bar level (Figure below). The ratio m/L , where L is the pitman length, called eccentricity (ξ), plays an important role in deciding crank radius (r) and stroke length (s). (Amalendu et al., 2003)

If a and b represent the lateral distances of knife bar at the end of a stroke, then $s + b = a$ Or

$$s + \sqrt{[(L-r)^2 - m^2]} = \sqrt{[(L+r)^2 - m^2]}. \text{ Squaring twice and rearranging yields,}$$

$$2r = \sqrt{\left(1 - \frac{4m^2}{4L^2 - s^2}\right)}. \text{ Neglecting } s^2 \text{ term before } 4L^2, \text{ then}$$

$$r = \frac{s}{2} \sqrt{1 - \xi^2} \dots\dots\dots 4.10i$$

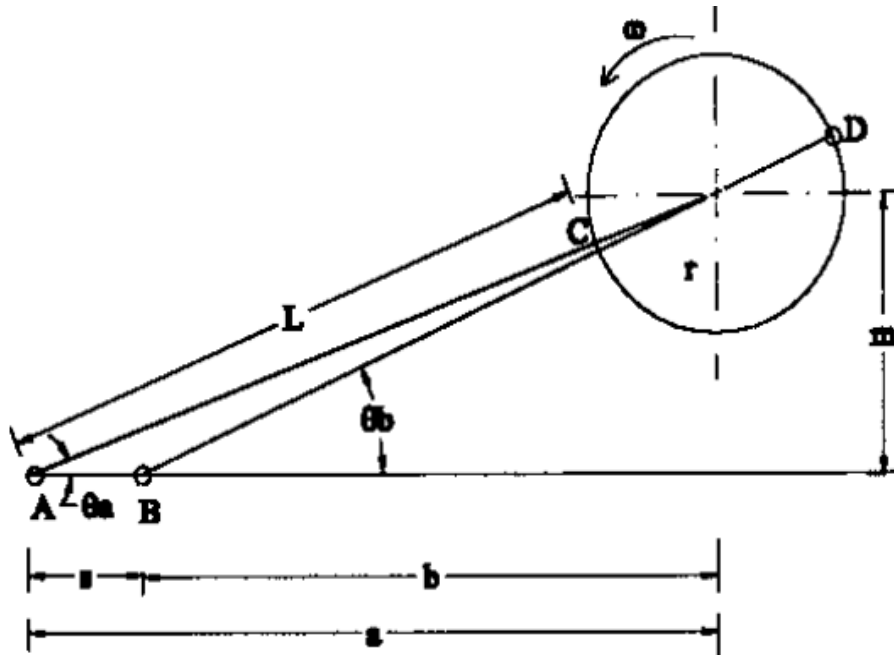


Figure 4.3. Pitman at extreme position

Since, ξ in equation above is less than unity, $s > 2r$ and for fixed stroke length, increase in ξ will reduce r . Furthermore, from figure above, the angles made by the pitman with horizontal at each end of the stroke will be (Amalendu et al., 2003)

$$\theta_a = \sin^{-1} \left(\frac{m}{L+r} \right) \text{ and } \theta_b = \sin^{-1} \left(\frac{m}{L-r} \right) \dots\dots\dots 4.10ii$$

The cutter bar assembly of the wheat crop reaper has the following layout. The crank radius and stroke length is determined based on the above principle.

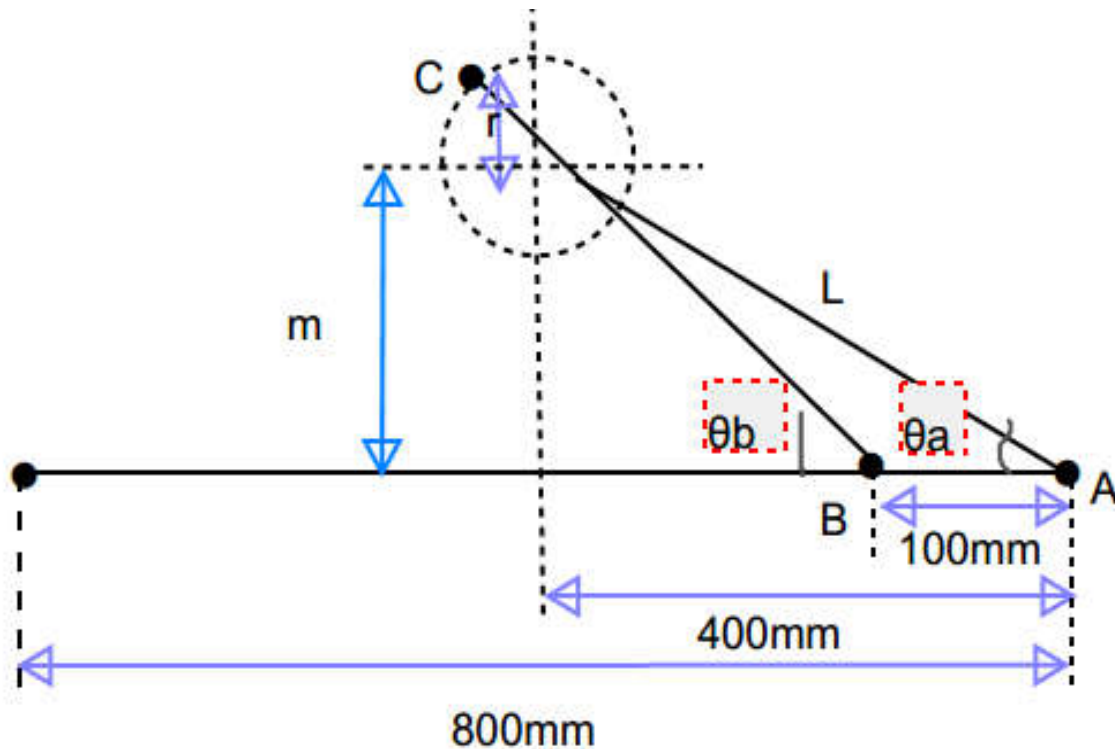


Figure 4.4. Free body diagram of cutter bar assembly

Taking Value of $m=70$ mm and $L= 325$ mm then by using equation 4.10i solve for r value.

$$\xi = \frac{m}{L} = \frac{70}{325} = 0.215$$

$$r = \frac{100}{2} \sqrt{1 - 0.215^2} = 48.831 \text{ mm and from equation 4.10ii}$$

$$\theta_a = \sin^{-1} \left(\frac{m}{L + r} \right) = \sin^{-1} \left(\frac{70}{325 + 48.831} \right) = 10.792^\circ$$

$$\theta_b = \sin^{-1} \left(\frac{m}{L - r} \right) = \sin^{-1} \left(\frac{70}{325 - 48.831} \right) = 14.683^\circ$$

For reapers weight of cutter bar per meter length is 20 to 22 N. let's take 20 N and weight (M_k) of 80 cm long cutter bar is 16N. Newton's second law $F = ma$, $m = \frac{F}{a}$. Taking gravitational acceleration $a = 9.81 \frac{m}{s^2}$, $M_k = \frac{16}{9.81} = 1.63 \text{ kg}$. For $V_k = 1 \text{ m/s}$ and $r = 48.831 \text{ mm}$ of a 80 cm long cutter bar using the above equation (4.7)

$$V = \omega \times r, \quad \omega = \frac{v}{r} = \frac{1}{0.049} = 20.303 \text{ rpm}$$

$$F_{i \max} = 1.63 \times 0.049 \times 412.212 = 32.923 \text{ N}$$

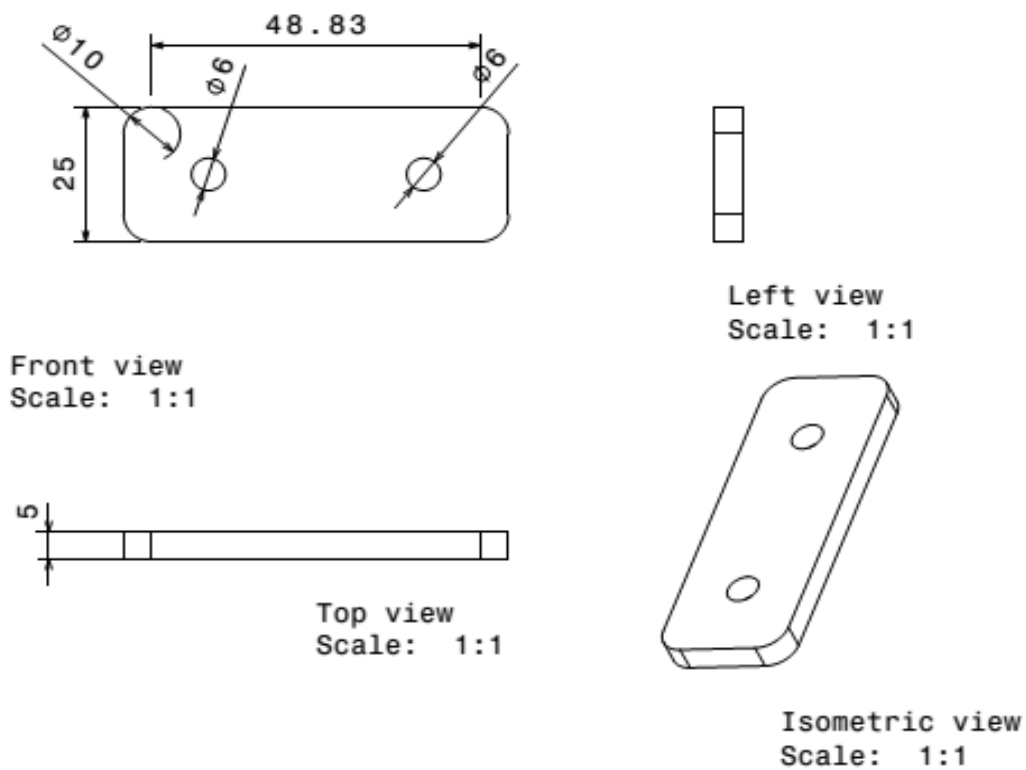


Figure 4.5. Front, top, side view and Isometric view of crank rod respectively

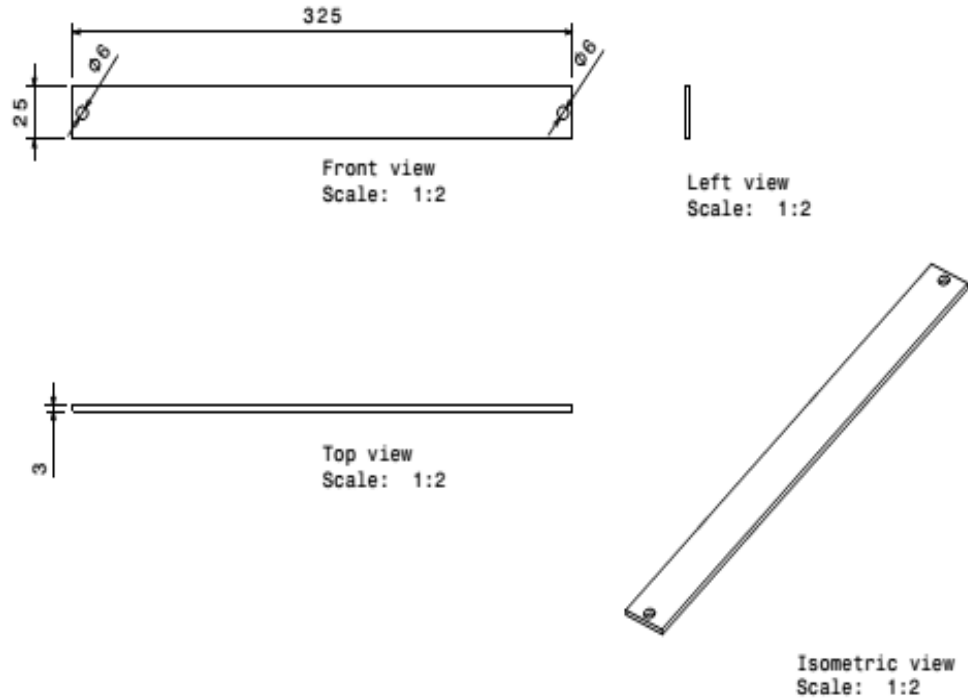


Figure 4.6. Front, top, side view and Isometric view of connecting rod respectively

4.4.3. Frictional force in the cutter bar

The frictional force (F_f) acts on the knife slides over the finger bar and was given by (Sharma and Mukesh, 2010)

$$F_f = F_{f1} + F_{f2} \dots\dots\dots (4.8)$$

F_{f1} = Force due to weight of cutter bar which was calculated by

$$F_{f1} = Mk \times f \dots\dots\dots (4.9)$$

$f = 0.2 - 0.3$, take average of it 0.25

$$F_{f1} = 1.63 \times 9.81 \times 0.25 = 3.998N$$

F_{f2} = force caused by normal component of force exerted by connecting rod on the knife

$$F_{f2} = \left[\frac{(F_c + F_{imax} + F_{f1})\tan\theta_b}{(1-f\times\tan\theta_a)} \right] f \dots\dots\dots (4.10)$$

Taking $L = 325$, $f = 0.25$ for wheat, $\theta_a = 10.792^\circ$ and $\theta_b = 14.683^\circ$

$$F_{f2} = \left[\frac{(68.75 \text{ N} + 32.923 \text{ N} + 3.998 \text{ N}) \tan 14.683}{(0.406 - 0.25 \times \tan 10.792)} \right] \times 0.25$$

$F_{f2} = 14.401 \text{ N}$. So, Frictional force in the cutter bar (F_f)

$$F_f = 4.725 \text{ N} + 14.401 \text{ N} = 19.646 \text{ N}$$

Therefore, total resisting force (F) acting on the cutter bar is calculated using equation (4.5)

$$F = F_c + F_f + F_{\text{imax}} = 68.75 \text{ N} + 19.646 \text{ N} + 32.923 \text{ N} = 121.319 \text{ N}$$

4.5. Power requirement for the Reaper

The Power required to overcome the resistance to motion of cutter bar (P) is given by (Sharma and Mukesh, 2010)

$$P = F \times v \dots \dots \dots (4.11)$$

Where, P = power in watts

F = resistive force, N

V = knife speed, m/s

Putting values $F = 121.319 \text{ N}$ and $v = 1 \text{ m/s}$ in equation above (4.11).

$$P = 121.319 \text{ N} \times 1 \frac{\text{m}}{\text{s}} = 121.319 \text{ watt.}$$

According to (Sharma and Mukesh, 2010) the average power produced by a man during continues work is 74.6 watts. Since power requirement for cutting wheat crops from Broad Bed Furrows is equal to 120.799 watts, the developed 80 cm size cutter bar length reaper for cutting of wheat crops is not feasible for one person. Number of persons required to operate the machine is $= \frac{121.319 \text{ watts}}{74.6 \text{ watts}} = 1.626$. Therefore, two persons is sufficient to operate the machine properly with good efficiency.

4.6. Wheel design for the Reaper

The Reaper's ground wheel, with external diameter of 400 mm, was designed as an integral part of the moving mechanism connected to the main frame at the down directly. The rim of wheel was made from mild steel flat iron 3 mm thick and 60 mm wide. Each wheel had six spokes

made from mild steel rods with diameter of 8 mm and length of 179 mm, and were welded to the rim and hub at the center of the wheel that served as bushing or shaft bearing, at equal interval (Figure 4.5). (Thomas and Brown, 2005) analyzed the shear strength (τ) of the ground wheel considering the wheel as thin-walled vessels.

$$\tau = \frac{T}{2A_m t_s} \dots\dots\dots (4.12)$$

Where: - T=the torque produced by the wheel (1.807 kNm)

A_m =the area of the wheel calculated based on the median diameter of the wheel

t_s = thickness of the wheel wall (0.003m).

r_m = the median radius of the wheel

r = the outer radius of the wheel (0.2m)

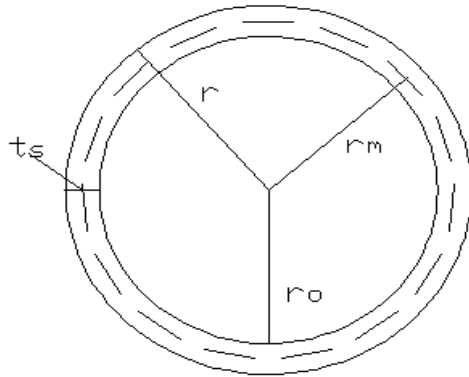


Figure 4.7. wheel parameters to be assumed as thin-walled vessel

$$A_m = \pi \times r_m^2 = \pi(r - 0.5 \times t_s)^2 \dots\dots\dots (4.13)$$

$$A_m = \pi(0.20 - 0.5 \times 0.003)^2 = 0.124\text{m}^2$$

Therefore, the shear stress on the wheel, $\tau = \frac{1.807 \times 10^3}{2 \times 0.124 \times 0.003} = 2.429 \text{ Mpa}$

Thus the calculated shear stress was much less than the maximum allowable shear stress of the mild steel sheet metal used in the construction of the wheel, 80.8 MPa, hence the wheel is safe for the design and operation.

The height of cut of 100mm above the ground level is to be maintained. (Sharma and Mukesh, 2010). Therefore, 400 mm diameter wheel and $60 \times 80 \times 130(l \times b \times h)\text{mm}^3$ cutter bar supports are fitted, which will be sufficient to maintain a cutter bar height of 100mm from ground level. The wheel is attached to the main frame in the middle by axle attached in the top bearing. To have a friction, a circular iron metal of 8 mm diameter is welded on the wheel.

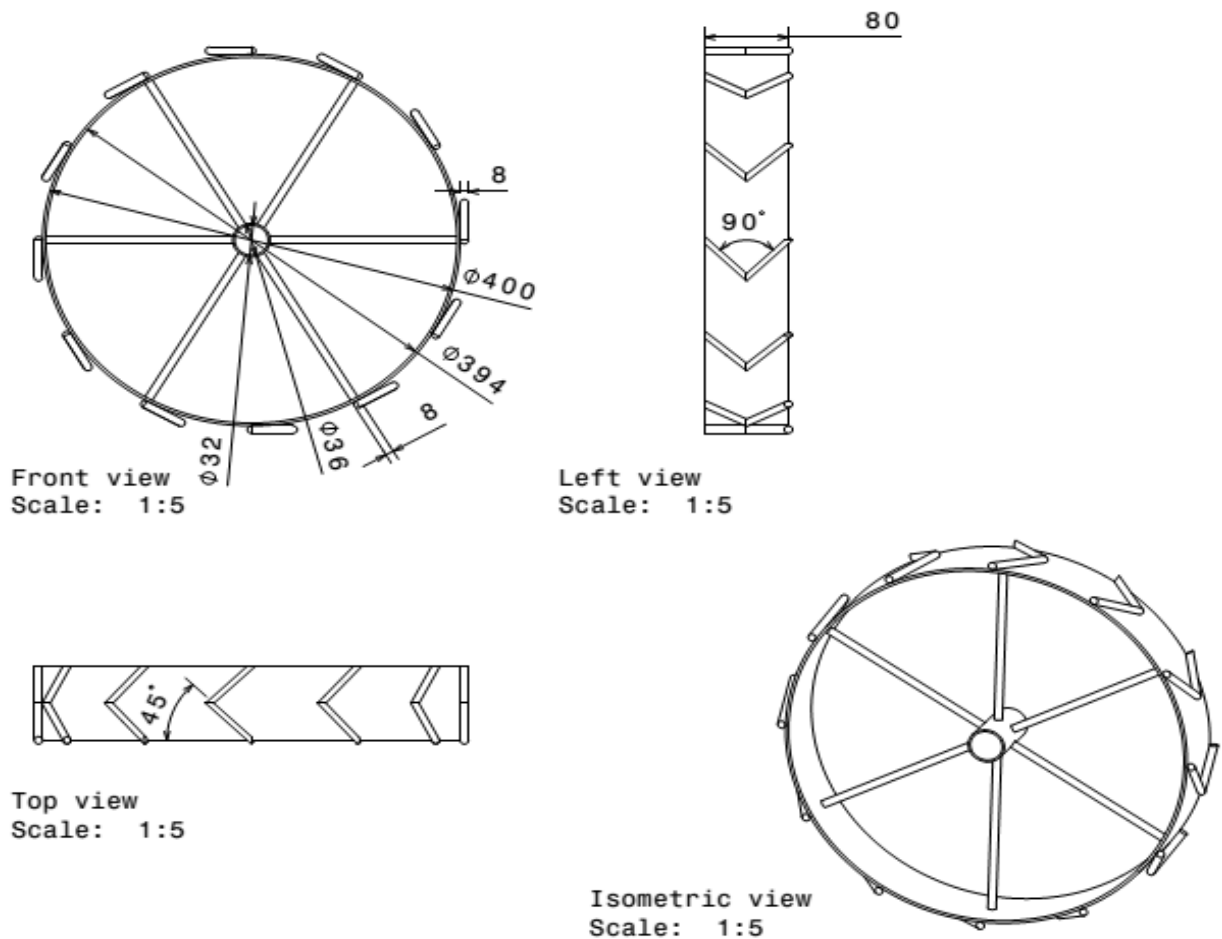


Figure 4.8. Front, top, side view and Isometric view of metal wheel respectively

4.7. Handle

Handle is used for providing the push and pull force from a human operator to move the Reaper from one place to another during harvesting operation. The handle was made from mild steel circular hollow pipe. It was designed with two different gripping ends on the mainframe at the top to suit the average standing elbow height of operators. The length of the handle is 520mm and diameter of the handle is 40 mm. The angle of handle is adjusted 30° to 45° in order to adjust

the height of operator and increase push or pull on the drive wheel. The designing of handle also approximate 100cm height is sufficient for pushing of any machinery. (Sharma and Mukesh, 2010). For the design 45° angles is selected.

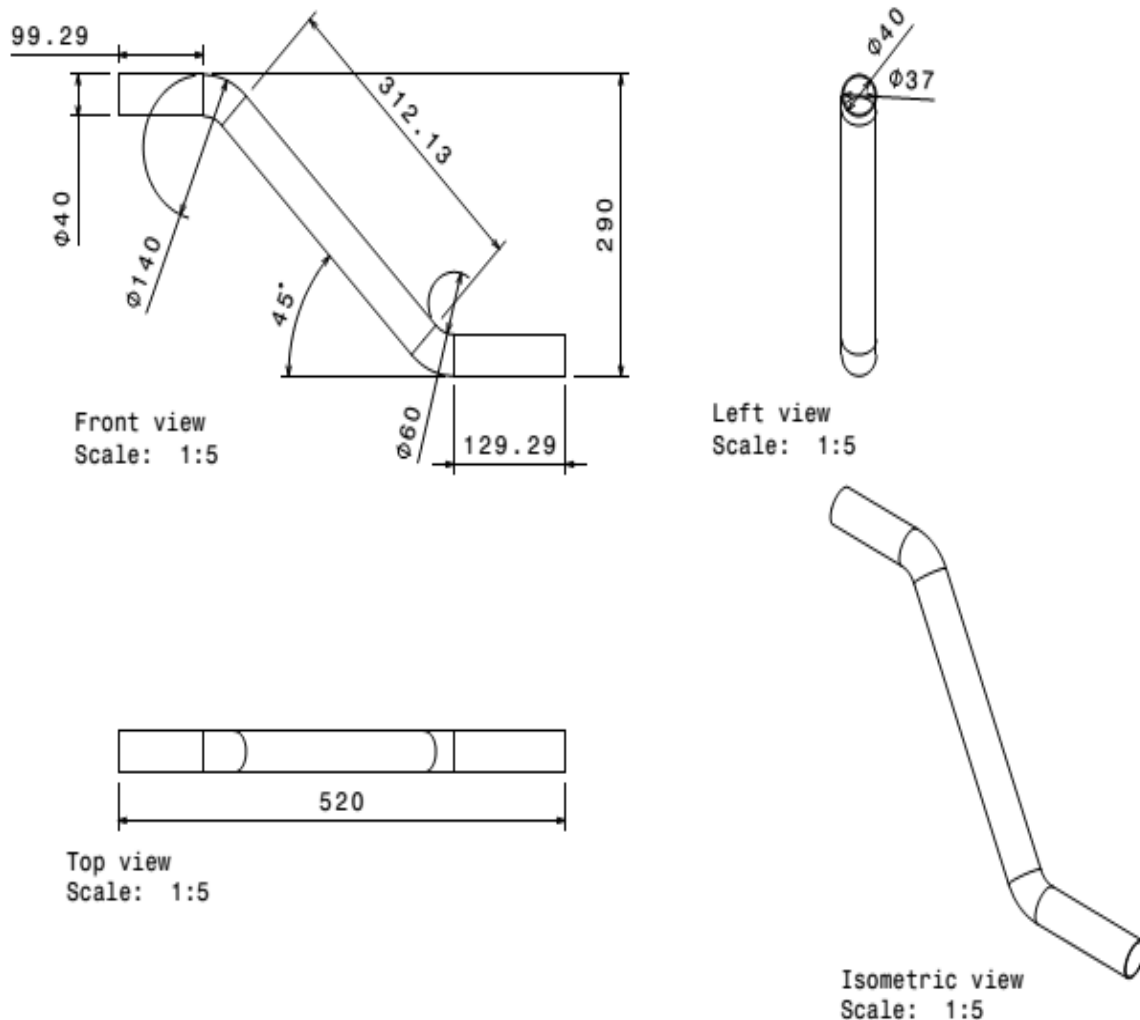


Figure 4.9. Front, top, side view and Isometric view of handle respectively

4.8. Selection and design of cutting unit of wheat crop Reaper

Cutter assembly consists of a sliding cutter plate and a stationery cutter plate. The cutters used are of triangular shape. In sliding cutter plate, cutter blade is riveted on 3 mm plate of mild steel and in stationery cutter plate; cutter blade is riveted on 5 mm plate. The stationary cutter plate can be directly bolted and fixed on main frame. Sliding cutter blade is provided with 2 slots of 100mm on its ends; it allows sliding motion to be in straight line. The knife cuts the crop by its

reciprocating action. The cutting unit of the reaper is designed and selected on the basis of following points.

4.8.1. The length of cutter bar

It is selected on the basis of row to row spacing of crops. In general, row to row spacing in wheat crop ranges 15-20 cm (Sharma and Mukesh, 2010). But this design considers width of BBM. So, let a cutter bar length $L_C = 0.75\text{m}$ is selected for the design. Because the design considers the width of BBM furrow which is around 0.8m and since it is almost equal to 1m including the bare holes on the two sides, no hindrance in collection and bundling of the cut crop manually. A reciprocating type cutter bar having 76 mm stroke length cutter blade and two cuts per stroke is selected for the design.

4.8.2. Number of knife section

$$\text{Number of knife section} = \frac{L_c}{\text{size of knife section}} \dots\dots\dots (4.14)$$

$$\text{Number of knife section} = \frac{0.75\text{m}}{0.076\text{m}} = 9.868$$

Take number of knife section 10. Adjusted length of cutter bar is therefore,

$$10 \times 0.076\text{m} = 0.76 \text{ m, take length of cutter bar } 0.8 \text{ m of mild steel.}$$

4.8.3. Size and shape of knife

Material for the knife section is high carbon steel. It is selected and designed based on the following parameters:

4.8.3.1. Gripping of stalk by cutting pitch

For normal cutting action the stalk should be pinched between cutting edge of knife section. The crop is cut by impact and shear action between the knife section and guard lip. For normal cutting action, the stalk should be pinched between cutting edge of knife and guard lip. This condition is satisfied when $\alpha + \beta = \phi_1 + \phi_2$ from equation 4.15 below. α Should range from 25- 35° for moisture content 14-22 % in wheat crop. (Sharma and S. Mukesh, 2010)

$$\angle \alpha + \angle \beta = \angle \phi_1 + \phi_2 \dots\dots\dots (4.15)$$

$\angle \alpha$ = Angle between cutting edge and axis of knife section

$\angle \beta$ = Angle between cutting edge and axis of axis of finger guard lip

$\angle \phi_1 + \phi_2$ = angle of friction between the crop and cutting edge of knife section and twin guard lip

Therefore, for operating speed of 0.8 m/s of machine, the knife section having an angle α of 31° or below is selected.

4.8.3.2. Rake angle, sharpness and thickness of cutting edge

The smaller rake angle and greater the sharpness, the greater is cutting ability of knife. The knives of small rake angle and sharp cutting edges become blunt more rapidly. The knives of rake angle of 22° are sharp for longer time but force requirement for cutting is higher as compared to rake angle of 19° .

But with existing tool grinders the rake angle obtained varies $22-25^\circ$. Thickness cutting knife should be not exceeding $25-30 \mu\text{m}$ for most of the cereals. (Sharma and Mukesh, 2010). So, thickness of knife $25 \mu\text{m}$ is selected for this design in order to have light weight and rake angle of 22° with sharp cutting edge is selected for the knife section.

4.8.3.3. Pitch of serrated knives

In order to avoid slipping off the stalks, the knives section should be serrated. If the pitch of serration is equal to stalk diameter, the stalk will choke the cutter and result in high power requirement. To avoid this pitch of serrated knives is selected two or three times smaller than the diameter of paddy or wheat stalk. The diameter of paddy or wheat stalk varies between 2 - 4 mm. The pitch of serrated knives is selected two three times smaller than the diameter of paddy and wheat stalk. i.e. pitch should be 1-1.2 mm. (Sharma and Mukesh, 2010). For this design 1.2mm pitch is selected because it can be designed and fabricated simply.

4.8.3.4. Clearance between knife

The quality of cutting is governed by the clearance between the cutting pair. A clearance of 0.5-1 mm can be selected. Best results are obtained when clearance between knives and ledger plates is maintained at 0.3 mm. For this design 0.75 mm clearance is selected which is average value.

4.8.3.5. Velocity of knife section

The cutting of stalk is greatly affected by knife speed. Therefore, the designer has to carefully design cutting mechanism and calculate speed of knife section. The velocity of knife section is expressed as:

$$V_k = R \times V_m \dots\dots\dots (4.16)$$

Where, V_k = knife velocity

V_m = forward speed of a machine

R = velocity ratio

For best results, according to (Sharma and Mukesh, 2010) for α of 31° the knife velocity should be 1m/s. the value of R falls between 1.3 - 1.4 with available cutter blades. Taking R as 1.4 and V_m of $0.8 \frac{m}{s}$ and putting values in equation above (4.16)

$$V_k = 1.3 \times 0.8 \text{ m/s} = 1.04 \frac{m}{s}, \text{ Take } V_k = 1 \text{ m/s.}$$

Also, it is known according to (Sharma and Mukesh, 2010)

$$V_k = \frac{X \times N_k}{30} \dots\dots\dots (4.17)$$

Where, x = stroke length

N_k = rpm of knife section

$$\text{Therefore, } N_k = \frac{30 \times V_k}{X} = \frac{30 \times 1 \frac{m}{s} \times 100 \frac{cm}{m}}{7.6 \text{ cm}} = 394.737 \text{ rpm. Let's take, } N_k = 400 \text{ rpm}$$

For a standard 76 mm knife section, the above velocity translates into 400 rpm of knife section. The actual average knife speed of cutter bar of reaper from equation (4.17) would be

$$V_k = \frac{N_k \times X}{30} = \frac{400 \times 7.6}{30 \times 100} = 1.013 \text{ m/s.}$$

This value is almost equal to the assumed and given standard.

4.8.3.6. Forward speed of a machine

The minimum permissible speed for 31° should be 0.8 m/s. The normal walking speed of human labour is about 0.7 to 0.8 m/s (Sharma and Mukesh, 2010). Therefore, forward speed of machine

can be selected as 0.8 m/s. On the basis of above discussed design parameters, the dimension of different components of crop cutting unit selected are given with figure and table below as specifications.

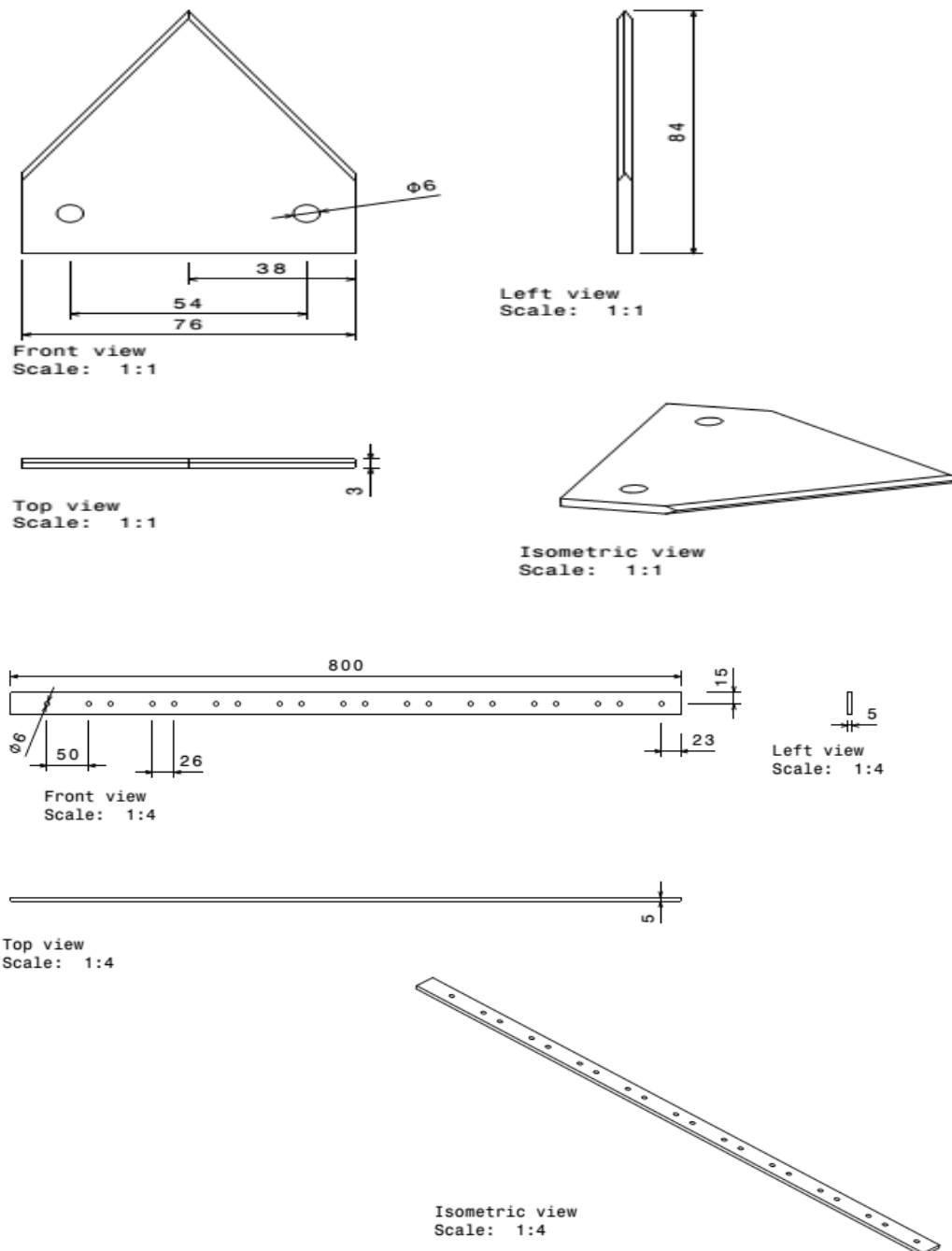


Figure 4.10. Front, top, side view and Isometric view of cutter blades and bar

Table 4.1. Specification of crop cutting unit of Reaper

No.		Particulars	Specifications
1.		Type of cutter bar	Reciprocating cutter bar
2.		Length of cutter bar	800 mm
3.		Knife section	From standard
	3.1	Type	Triangular
	3.2	Blade	Serrated
	3.3	Length $\times$ height	76 mm $\times$ 84 mm
	3.4	Angle between cutting edge & axis of knife section (α)	31°
	3.5	Rake angle	22°
	3.6	Thickness of cutting edge	25 μ m
	3.7	Pitch of serration	1.2 mm
	3.8	Clearance between knife and twin guard	0.75 mm
	3.9	Material	High carbon steel
4.		Height of cutter bar above ground level	Up to 100 mm

The shape of the cutter blade is triangular; this is also assumed to serve as crop dividing in this compact wheat crop harvester.

4.9. Design of power transmission system

The main power transmission components employed in agricultural machines are v-belt, chain drive, gear drive and combination of belt and chain, belt and gear and gear and chain.(Sharma and Mukesh, 2010). The 2.7 KW(3.671 hp), 4000 rpm and rope start type of diesel engine act as the driving force to operate the cutting and conveying mechanism of the machine is selected and move forward by pushing it from the back. Diesel engine is selected because diesel engine has good efficiency, power and its availability. The complete design of power transmission mechanism i.e. from engine to cutting and conveying mechanism of the machine is discussed below.

4.9.1. Selection of belt

The belts or ropes are used to transmit power from one shaft to another by means of pulleys which rotate at the same speed or at different speeds. Following are the various important factors upon which the selection of a belt drive depends: Speed of the driving and driven shafts, Speed reduction ratio, Power to be transmitted, Centre distance between the shafts, Positive drive requirements, Shafts layout, Space available and Service conditions. (Khurmi and Gupta, 2005)

The belt drives primarily operate on the friction principle. i.e. the friction between the belt and the pulley is responsible for transmitting power from one pulley to the other. In other words the driving pulley will give a motion to the belt and the motion of the belt will be transmitted to the driven pulley. (Laukik et al., 2014)

V-belt length and arc of contact

The v-belt is mostly used in the factories and workshops, where a great amount of power is to be transmitted, from one pulley to another, when the two pulleys are very near to each other. Belts are generally used to connect parallel shafts so that the pulleys rotate in the same direction or in the opposite direction. The belt length for an open drive is approximated by the following formula. (Khurmi and Gupta, 2005)

$$L = 2C + \frac{\pi}{2}(D + d) + \frac{(D-d)^2}{4C} \dots\dots\dots (4.18)$$

And for the crossed belt drive the length is given by the following formula.

$$L = 2C + \frac{\pi}{2}(D + d) + \frac{(D+d)^2}{4C} \dots\dots\dots (4.19)$$

Where, D and d = are the outside sheave diameters for large and small pulleys respectively

C = Center to Center distance between sheaves

L = Length of Belt

For the open belt drive, the angle of contact in (rad) is calculated by the following formula. While determining the angle of contact, it must be remembered that it is the angle of contact at the smaller pulley, if both the pulleys are of the same material. The more angle of contact the more power is to be transmitted.

Angle of contact or lap for open belt drive, (Khurmi and Gupta, 2005)

$$\theta = (180^\circ - 2\alpha) \times \frac{\pi}{180} \text{rad} \dots \dots \dots (4.20)$$

$$\sin \alpha = \frac{d_1 - d_2}{2C}$$

Angle of contact or lap for cross belt drive, (Khurmi and Gupta, 2005)

$$\theta = (180^\circ + 2\alpha) \times \frac{\pi}{180} \text{rad} \dots \dots \dots (4.21)$$

$$\sin \alpha = \frac{d_1 + d_2}{2C}$$

Speed of V-belt drives

As a belt bends to conform to the sheave curvature, the outer section stretches and the inner section is compressed. Pitch diameters, rather than outside diameters, should always be used in calculating speed ratios and belt speeds. (Ajit et al., 2012). The belt speed is calculated as:

$$V = \pi N_2 d = \pi N_3 D \dots \dots \dots (4.22)$$

Where, v = belt speed in m/s

N_2, N_3 = angular speeds of rotation of sheaves 2 and 3, respectively, in rpm

D, d = pitch diameters of pulleys large and small, respectively, m

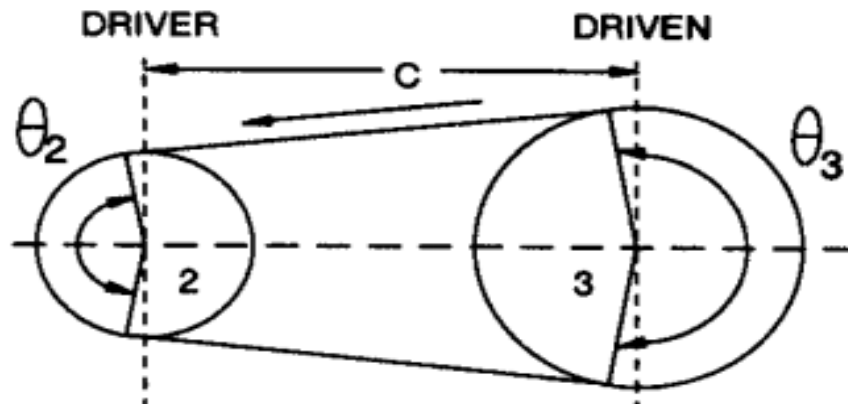


Figure 4.11. Open pulley arrangement

Velocity ratio of a belt drive

It is the ratio between the velocities of the driver and the follower or driven. It may be expressed, mathematically, as discussed below:

Let, d_1 = Diameter of the driver,

d_2 = Diameter of the follower,

N_1 = Speed of the driver in r.p.m.,

N_2 = Speed of the follower in r.p.m.,

Length of the belt that passes over the driver, in one minute = $\pi d_1 N_1$. Similarly, length of the belt that passes over the follower, in one minute = $\pi d_2 N_2$. Since the length of belt that passes over the driver in one minute is equal to the length of belt that passes over the follower in one minute, therefore, $\pi d_1 N_1 = \pi d_2 N_2$, when there is no slip, then $V_1 = V_2$. (Khurmi and Gupta, 2005)

And velocity ratio, $\frac{N_2}{N_1} = \frac{d_1}{d_2}$(4.23)

The velocity ratio of a belt drive may also be obtained as discussed below. It is known that the peripheral velocity of the belt on the driving pulley, (Khurmi and Gupta, 2005)

$$V_1 = \frac{\pi d_1 N_1}{60} \text{(4.24)}$$

And peripheral velocity of the belt on the driven pulley,

$$V_2 = \frac{\pi d_2 N_2}{60} \text{(4.25)}$$

4.9.2. Selection and dimensions of pulley (from engine to spur gear box)

The pulleys are used to transmit power from one shaft to another by means of flat belts, v-belts or ropes. The diameter of the pulley may be obtained either from velocity ratio consideration or centrifugal stress consideration. It is known that the centrifugal stress induced in the rim of the pulley, (Khurmi and Gupta, 2005)

$$\sigma_t = \rho \times V^2 \text{ (4.26)}$$

Where, σ_t =Centrifugal stress or tensile stress in the pulley rim, Centrifugal stress or tensile

stress in the pulley rim = 4.5 MPa = 4.5×10^6 N/m²

ρ = Density of the rim material, 7200 kg/m³ for cast iron

V = Velocity of the rim

The following are the diameter of pulleys in mm for flat and V-belts. 20, 22, 25, 28, 32, 36, 40, 45, 50, 56, 63, 71, 80, 90, 100, 112, 125, 140, 160, 180, 200, 224, 250, 280, 315, 355, 400, 450, 500, 560, 630, 710, 800, 900, 1000, 1120, 1250, 1400, 1600, 1800, 2000, 2240, 2500, 2800, 3150, 3550, 4000, 5000, 5400. The first six sizes (20 to 36 mm) are used for v-belts only. (Khurmi and Gupta, 2005)

Let, N_1 = Engine rpm

d_1 = Diameter of small pulley (driving pulley)

N_2 = Input to spur gear box rpm

d_2 = Diameter of Large pulley (driven pulley)

Calculation of pulley diameter starts from smaller pulley diameter. The material selected for the pulleys cast iron, because of their low cost.

From equation (4.23) $V^2 = \frac{\sigma_t}{\rho} = \frac{4.5 \times 10^6}{7200} = 625$, $V = \sqrt{625} = 25$ m/s and putting in equation (4.24)

$d_1 = \frac{V \times 60}{\pi \times N_1} = \frac{25 \times 60}{\pi \times 4000} = 0.119$ m = 119mm, take $d_1 = 125$ mm from a standard. To get reduced speed rpm at the cutter bar of a reaper let select standard diameter of driven pulley diameter (d_2) aim to get optimum angular rpm speed (N_2). $d_2 = 2 \times d_1 = 2 \times 125 = 250$ mm. So, take $d_2 = 250$ mm which is also in the standard.

Velocity of pulley

Engine speed in rpm is already given $N_1 = 4000$ rpm and from equation (4.23) it can be derived that, $N_1 d_1 = N_2 d_2$. By using this equation lets calculate rpm speed which is in put to spur gear box.

$$N_2 = \frac{N_1 \times d_1}{d_2} = \frac{4000 \times 0.125}{0.25} = 2000 \text{ rpm.}$$

So, take $N_2 = 2000$ rpm

The velocity ratio of a belt drive may also be calculated as discussed above. The peripheral velocity of the belt on the driving pulley by using equation (4.24),

$$V_1 = \frac{\pi \times 0.125 \times 4000}{60} = 26.18 \frac{\text{m}}{\text{s}}$$

And peripheral velocity of the belt on the driven pulley by using equation (4.25),

$$V_2 = \frac{\pi \times 0.25 \times 2000}{60} = 26.18 \text{ m/s.}$$

The values of V_1 and V_2 are equal; this indicates that there is no slip between the belts and pulleys. So, belt slippage is almost negligible.

Belt length and angle of contact or lap

Center distance between the two pulleys(C) is given by $C = 2 \times d_2$. But, of course space availability matters. $C = 2 \times 250 = 500\text{mm}$. Therefore, with in available space let's take the value center distance for pulleys between the engine and spur gear box, $C = 500 \text{ mm}$. Belt length for V-belt pulley between engine and spur gear box is calculated by using equation (4.15), for open belt systems.

$$L = 2 \times 500\text{mm} + \frac{\pi}{2}(250\text{mm} + 125\text{mm}) + \frac{(250\text{mm} - 125\text{mm})^2}{4 \times 500\text{mm}}$$

$$L = 1000\text{mm} + 589.049\text{mm} + 7.713\text{mm}$$

$$L = 1596.862\text{mm}$$

Subtracting 36 for A type belt it is found, the inside length of belt= $1596.862 - 36 = 1560.862 \text{ mm}$. From a standard, the nearest standard inside length of v-belt is 1600mm. therefore, pitch length of the belt.

$$L = 1600 + 36 = 1636\text{mm}$$

Angles of contact or lap for open belt pulley drive from equation (4.20)

$$\theta = (180^\circ - 2\alpha) \times \frac{\pi}{180} \text{ rad and } \sin\alpha = \frac{d_1 - d_2}{2C}$$

,

$$\sin\alpha = \frac{125 - 250}{2 \times 500} = \frac{-125}{1000} = -0.125$$

$$\alpha = \sin^{-1}(-0.125) = -7.181$$

$$\text{Therefore, } \theta = (180^\circ - 2(-7.181)) \times \frac{\pi}{180} \text{ rad}$$

$$\theta = (180^\circ + 14.362) \times 0.017 \text{ rad} = 3.304 \text{ rad}$$

$$\theta = 3.304 \text{ rad}$$

The calculated value of angle of wrap, θ is given in radian. To change the unit in degree,

$$1^\circ = \frac{\pi}{180} \text{ (Sharma and Mukesh, 2010).}$$

$$\text{Therefore, } \theta = \frac{1^\circ \times 3.304 \text{ rad}}{0.017 \text{ rad}} = 194.362^\circ$$

$$\theta = 194.362^\circ,$$

This angle of contact or lap is for small pulley since the two pulleys are made of the same material.

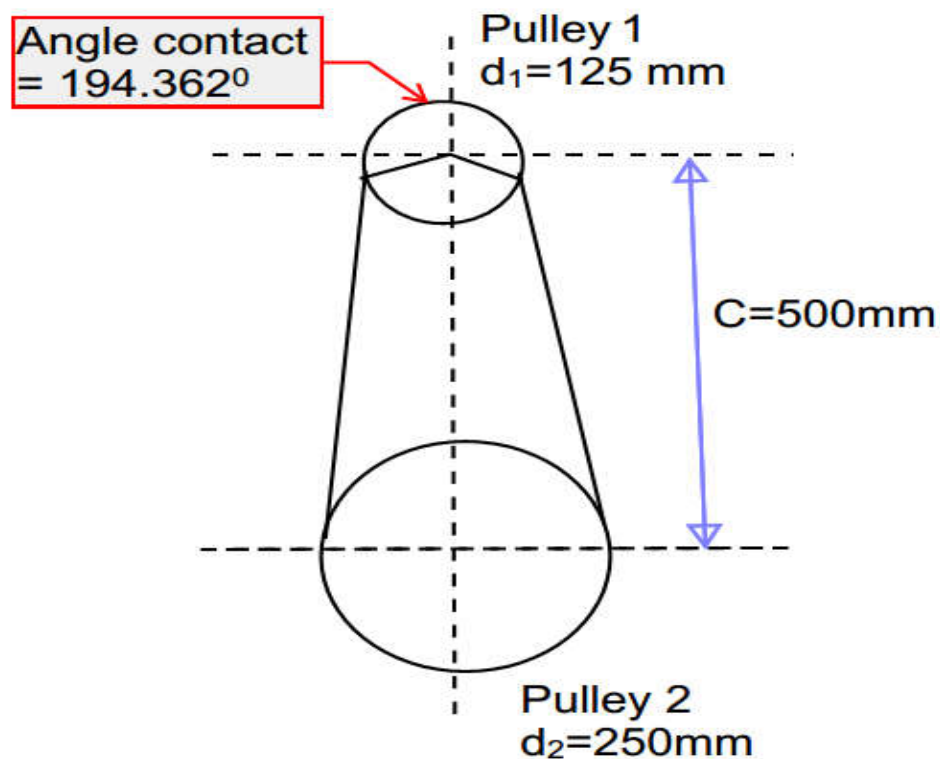


Figure 4.12. Open belt drive system between engine and spur gear box

Belt tension

Power for application from diesel engine is 2.7 kW or 3.671hp. Let find tension of belt in tight side T_1 and slack side T_2 from equation below. The following expression gives the relation

between the tight side T_1 and slack side tensions T_2 , in terms of coefficient of friction and the angle of contact.

$$2.3 \log \left(\frac{T_1}{T_2} \right) = \mu \theta \operatorname{Cosec} \beta \dots \dots \dots (4.27)$$

Where, μ = Coefficient of friction between the belt and sides of the groove.

θ = angle of contact, in radians, *i.e.* angle subtended by the arc, along which the belt touches the pulley, at the centre)

β = angle of grove

The wedging action of the v-belt in the groove of the pulley results in higher forces of friction. Usually the groove angles of 32° to 38° are used

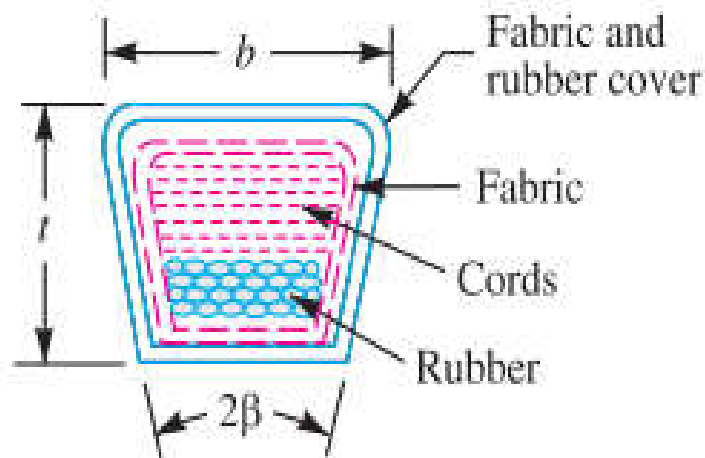


Figure 4.13. cross section of v-belt

Taking angle of groove $2\beta=38^\circ$, $\beta=19^\circ$ and $\mu = 0.3$ because rubber belt is selected.

$$\log \left(\frac{T_1}{T_2} \right) = \frac{(0.3 \times 3.304 \operatorname{cosec} 19)}{2.3} = 1.324$$

Taking antilog of 1.324, $\frac{T_1}{T_2} = 21.086$

$$T_1 = 21.86 T_2 \dots i$$

Power Transmitted per belt, $P = (T_1 - T_2) V$

$$2.7 \text{ kw} = (T_1 - T_2) 26.18 \frac{m}{s}$$

$T_1 - T_2 = 0.103 \text{ kN}$...ii Substituting i into ii

$21.086T_2 - T_2 = 0.103 \text{ kN}$, $T_2 = 20.086T_2 = 0.103 \text{ kN}$, $T_2 = 0.005 \text{ kN}$ and $T_1 = 0.108 \text{ kN}$

In put values: $P = 2.7 \text{ KW}$, $V_b = 26.18 \text{ m/s}$, $\theta = 3.304 \text{ rad}$ and $\mu = 0.3$ rubber belts used,

Then $T_1 = 0.108 \text{ kN}$ and $T_2 = 0.005 \text{ kN}$,

Power transmitted per belt, $P = (T_1 - T_2)v_b = (0.108 - 0.005)26.18 = 2.697 \text{ kW}$

Number of belts required = $\frac{\text{Total power transmitted}}{\text{Power transmitted per belt}} = \frac{2.7 \text{ KW}}{2.697 \text{ KW}} = 1.001 \approx 1$

Therefore, number of v-belts required here is one.

Pulley width (B) and belt width (b)

If the width of the belt is known, then width of the pulley or face of the pulley (B) is taken 25% greater than the width of belt. $B = 1.25b$, where b = width of belt.

For power rating of 2.7 kW and minimum pitch diameter of 125 mm pulley, it is B type pulley v-belts pulley from standard and given in appendix 3. From this belt width $b = 17 \text{ mm}$ and thickness (t) = 11 mm. $B = 1.25 \times b = 1.25 \times 17 = 21.25 \text{ mm}$. usually the groove angles of 32° to 38° are used. For the design select groove angle of 38° .

The thickness of the pulley rim (t): varies from $\frac{D}{300} + 2 \text{ mm}$ to $\frac{D}{200} + 3 \text{ mm}$ for single belt.

$t = 2.417$ to 3.625 mm for drive pulley ($D = 125 \text{ mm}$)

$t = 2.833$ to 4.25 mm for driven pulley ($D = 250 \text{ mm}$)

Dimensions of arms

- The number of arms taken as 4 for pulley diameter from 200 mm to 600 mm
- The pulleys less than 200 mm diameter are made with solid disc instead of arms. The thickness of the solid web is taken equal to the thickness of rim measured at the centre of the pulley face. (Khurmi and Gupta, 2005)

Note: Selection of pulley must be based on the dimension of pulley analyzed above

4.9.3. Shaft design

A shaft is a rotating machine element which is used to transmit power from one place to another. The power is delivered to the shaft by some tangential force and the resultant torque (or twisting moment) set up within the shaft permits the power to be transferred to various machines linked up to the shaft. In order to transfer the power from one shaft to another, the various members such as pulleys, gears etc., are mounted on it. These members along with the forces exerted upon them causes the shaft to bending. In other words, we may say that a shaft is used for the transmission of torque and bending moment. The various members are mounted on the shaft by means of keys or splines. The material used for shafts should have the following properties. It should have high strength; it should have good machinability, low notch sensitivity factor, good heat treatment properties and high wear resistant properties. (Khurmi and Gupta, 2005)

Determination of shaft diameter

When the shaft is subjected to a twisting moment (or torque) then the diameter of the shaft may be obtained by using the torsion equation. (Khurmi and Gupta, 2005)

$$T = \frac{\pi}{16} \times \tau \times d^3 \quad \dots\dots\dots (4.27)$$

The twisting moment (T) may be obtained by using the following relation:

$$T = \frac{P \times 60}{2\pi N} \quad \dots\dots\dots (4.28)$$

T = Twisting moment (Torque) acting upon the shaft

τ = Torsional shear stress

d = Diameter of shaft

P = Power transmitted (in kilowatts) by the shaft

N = Speed of the shaft in rpm

When the shaft is subjected to a bending moment then the maximum stress (tensile or compressive) is given by the bending equation. (Khurmi and Gupta, 2005)

$$M = \frac{\pi}{32} \times \sigma_b \times d^3 \dots\dots\dots(4.29)$$

M = Bending moment

σ_b =Bending Stress

When the shaft is subjected to combined twisting moment and bending moment, then the shaft must be designed on the basis of the two moments simultaneously. Various theories have been suggested to account for the elastic failure of the materials when they are subjected to various types of combined stresses. The Maximum shear stress theory or Guest's theory. It is used for ductile materials such as mild steel. According to maximum normal stress theory, the maximum normal stress in the shaft, (Khurmi and Gupta, 2005)

$$\sigma_{b \max} = \frac{1}{2} \sigma_b + \frac{1}{2} \sqrt{(\sigma_b)^2 + 4\tau^2} \dots\dots\dots(4.30)$$

$$M_e = \frac{1}{2} [M + \sqrt{M^2 + T^2}] = \frac{\pi}{32} \times \sigma_b \times d^3 \dots\dots\dots(4.31)$$

The expression $\frac{1}{2} [M + \sqrt{M^2 + T^2}]$ is known as equivalent bending moment and is denoted by M_e . From this expression, diameter of the shaft d is obtained. (Khurmi and Gupta, 2005). In actual practice, the shafts are subjected to fluctuating torque and bending moments. In order to design such shafts like line shafts and counter shafts, the combined shock and fatigue factors must be taken into account for the computed twisting moment, T and bending moment, M . Thus for a shaft subjected to combined bending and torsion, (Khurmi and Gupta, 2005)

$$T_e = \sqrt{(K_m \times M)^2 + (K_T \times T)^2} \dots\dots\dots(4.32)$$

The equivalent bending moment:

$$M_e = \frac{1}{2} [K_m \times M + \sqrt{(K_m \times M)^2 + (K_t \times T)^2}] \dots\dots\dots(4.33)$$

K_m = Combined shock and fatigue factor for bending.

K_t = Combined shock and fatigue factor for torsion.

The shaft was initially decided to be fabricated from ductile material, mild steel rod. Hence, the design was based on ductile material whose strength is controlled by maximum shear stress.

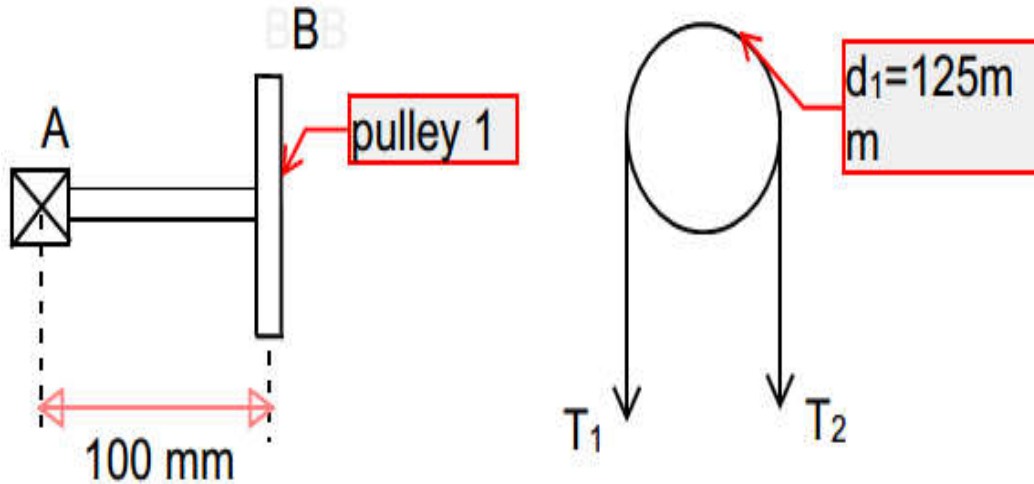


Figure 4.14. Free body diagram of shaft and belt pulley arrangement from engine

This shaft transmits power from the source to the pulleys and carries machine parts such as tensioned belts and bearing, therefore they are subjected to bending in addition to twisting then stresses due to combined torsional and bending loads are used to determine the shaft diameter. It is known that torque transmitted by shaft,

$$T = \frac{P \times 60}{2 \times \pi \times N} = \frac{2.7 \text{ kw} \times 60}{2 \times \pi \times 4000} = 6.446 \text{ Nm}$$

Since the overhang of the pulley is taken 100 mm, bending moment of the shaft due to belt tension assuming weight pulley negligible.

Material selection: based on the availability in country and strength mild steel is selected. Properties of mild steel, density = 7861.093 kg/m³ and maximum tensile strength = 500 Mpa, yield

Strength = 250 Mpa. Therefore, $\sigma_b = \frac{\text{yield strength}}{\text{factor of safety}}$.

Let take factor of safety be 1.5 and $\sigma_b = 166.67 \text{ Mpa}$. Bending moment (M) = $(T_1 + T_2) \times L = (0.108 \text{ kN} + 0.005 \text{ kN}) \times 0.1 \text{ m} = 11.3 \text{ Nm}$. From appendix 1, taking $k_m = 1.5$ and $k_t = 1.0$

$$M_e = \frac{1}{2} \left[K_m \times M + \sqrt{(K_m \times M)^2 + (K_t \times T)^2} \right] = \frac{\pi}{32} \times \sigma_b \times d^3$$

$$\frac{1}{2} \left[1.5 \times 11.3 + \sqrt{(1.5 \times 11.3)^2 + (1 \times 6.446)^2} \right] = \frac{\pi}{32} \times 166.667 \times 10^6 \times d^3$$

$$17.542 = 16362494.46d^3$$

From this $d = 10.235\text{mm}$. Let's take $d = 20\text{mm}$ from standard on safer side.

4.9.4. Gear selection

The material used for the manufacture of gears depends upon the strength and service conditions like wear, noise etc. The gears may be manufactured from metallic or non-metallic materials. The slipping of a belt or rope is a common phenomenon, in the transmission of motion or power between two shafts. The effect of slipping is to reduce the velocity ratio of the system. In precision machines, in which a definite velocity ratio is of importance, the only positive drive is by gears or toothed wheels. A gear drive is also provided, when the distance between the driver and the follower is very small.

The following are the advantages and disadvantages of the gear drive as compared to other drives, i.e. belt, rope and chain drives: It transmits exact velocity ratio, may be used to transmit large power, may be used for small centre distances of shafts, has high efficiency, has reliable service and has compact layout, the manufacture of gears requires special tools and equipment, therefore it is costlier than other drives. This is the only side effect of gear.

4.9.4.1. Spur gear design

For compact transmission design it is desirable to use gears. It is very compact, takes very less space which is required in this machine. The main advantage of gear drive is that it transmit same velocity ratio and also it is used to transmit a very large power with very good reliable service. (Laukik et al., 2014)

The tooth profile of the 20° full depth involutes' system may be cut by hobs. The increase of the pressure angle from $14\frac{1}{2}^\circ$ to 20° results in a stronger tooth, because the tooth acting as a beam is wider at the base.



Figure 4.15. Spur Gear

Interference may only be avoided, if the point of contact between the two teeth is always on the involutes profiles of both the teeth. The minimum numbers of teeth on the pinion which will mesh with any gear without interference are given in the following table..(Khurmi and Gupta, 2005)

Table 4.2. The minimum numbers of teeth on the pinion

S. No.	Systems of gear teeth	Minimum number of teeth on the pinion
1	$14\frac{1}{2}^\circ$ Composite	12
2	$14\frac{1}{2}^\circ$ Full depth involutes	32
3	20° Full depth involutes	18
4	20° Stub involutes	14

So, let's take Spur gearbox consist of pinion with 18 teeth and let's take four times pinion to have good speed reduction. So, gear with 72 teeth desired.

$$N_2 T_2 = N_3 T_3 \dots \dots \dots (4.34)$$

Where, T_2 = Pinion teeth

N_2 = input rpm

N_3 = output rpm

T_3 = gear teeth

$N_2=2000$, $T_3 = 72$ teeth, $T_2 = 18$ teeth. Putting these value in equation above

$$N_3 = \frac{N_2 \times T_2}{T_3} = N_3 = \frac{2000 \times 18}{72} = 500, \text{ take } N_3 = 500 \text{ rpm}$$

Shaft design for spur gear

Input rpm to spur gearbox is $N_2=2000$ rpm. by using equation (4.28) for torque calculation $T =$

$$\frac{2.7kw \times 60}{2 \times \pi \times 2000} = 12.89 \text{ Nm}$$

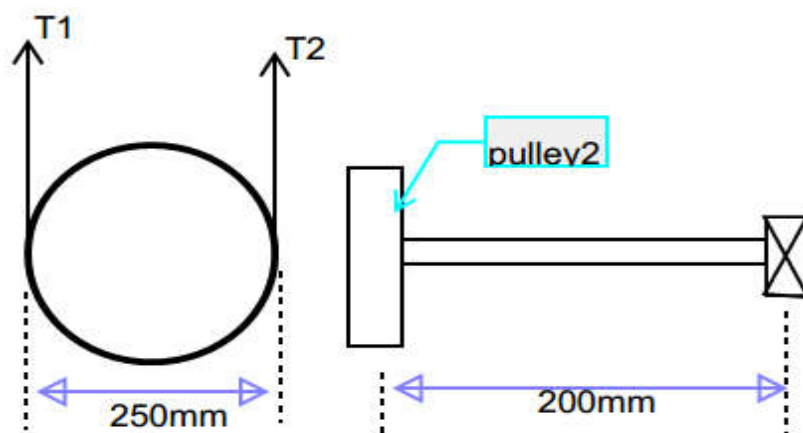


Figure 4.16. Tension on pulley

Using values of T_1 and T_2 from above calculation moment can be calculated, $M = (0.108\text{kN} + 0.005\text{kN}) 0.2\text{m} = 22.6\text{Nm}$. Using equation (4.33) shaft size can be determined.

$$\frac{1}{2} \left[1.5 \times 22.6 + \sqrt{(1.5 \times 22.6)^2 + (1 \times 12.89)^2} \right] = \frac{\pi}{32} \times 166.667 \times 10^6 \times d^3$$

$$35.08 = 16362494.46d^3$$

From this calculation , $d = 12.895\text{mm}$. On the safer side, let's take $d = 15\text{mm}$ and selected material is mild steel.

4.9.4.2. Bevel gear selection and design

The bevel gears are used for transmitting power at a constant velocity ratio between two shafts whose axes intersect at a certain angle. Bevel gearbox is used to change the direction of motion by 90° . This type of gearbox is used because there was a need to transmit power to two mechanisms i.e. slider crank mechanism and collecting mechanism.(Khurmi and Gupta, 2005)



Figure 4.17. Bevel gear

Based on availability in the market it is important to select number of teeth appropriate for the designed machine. Accordingly, Input bevel gear teeth 10 and output bevel gear teeth 16. (Khurmi and Gupta, 2005)

$$N_4 T_4 = N_5 T_5 \dots \dots \dots (4.35)$$

Where, T_4 = Input to bevel gear teeth

T_5 = output of bevel gear teeth

$N_4 = N_3$ = Input rpm to bevel gear = 500 rpm

$N_4 = 500\text{rpm}$, $T_4 = 10$ and $T_5 = 16$ using equation (4.35), N_5 can be calculated

$$N_5 = \frac{N_4 \times T_4}{T_5} = \frac{500 \times 10}{16} = 312.5 \text{ rpm}$$

Lets, take final rpm at cutter is $N_5 = 312.5 \text{ rpm}$

Design of belt and pulley for bevel gear output shaft:

As usual a v-belt is selected. Because v-belt drive gives compactness due to small distance between centers of pulleys. Center to center distance $C = 400\text{mm}$, by using equation (4.18) belt length can be calculated.

$$L = 2 \times 400 + \frac{\pi}{2}(90 + 80) + \frac{(90 - 80)^2}{4 \times 400} = 1067.133\text{mm}$$

Subtracting 36 for A type belt it is found, the inside length of belt = $1067.133 - 36 = 1031.133\text{mm}$. From a standard, the nearest standard inside length of v-belt is 1067mm. therefore, pitch length of the belt

$$L = 1067 + 36 = 1103\text{mm}$$

Let assume the smaller diameter from the standard $d_1=80\text{mm}$ and $D_2=90\text{mm}$. these small diameter pulleys are light weight and to provide motion for flat belts.

For power rating of 2.7 kW and minimum pitch diameter of 75 mm pulley, it is A type v-belts pulley from standard and given in appendix 3. From this top width of belt $(b) = 13\text{ mm}$ and thickness $(t) = 8\text{mm}$. $B = 1.25 \times b = 1.25 \times 13 = 16.25\text{mm}$. usually the groove angles of 32° to 38° are used. For the design select groove angle of 38° .

The thickness of the pulley rim (t) : varies from $\frac{D}{300} + 2\text{ mm}$ to $\frac{D}{200} + 3\text{ mm}$ for single belt.

$$t = 2.267 \text{ to } 3.4 \text{ mm for drive pulley } (D = 80 \text{ mm})$$

$$t = 2.3 \text{ to } 3.45 \text{ mm for driven pulley } (D = 90 \text{ mm}).$$

4.10. Coupling selection

A coupling is a device used to make permanent or semi-permanent connection where as a clutch permits rapid connection or disconnection at the will of the operator. Shaft couplings are use in machinery for several purposes, the most common of which are the following. To provide for misalignment of the shafts, introduce mechanical flexibility, reduce the transmission of shock loads from one shaft to another, introduce protection against overloads and should have no projecting parts. (Khurmi and Gupta, 2005)

Sleeve or muff-coupling from the market is selected to connect the two shafts together at their ends for the purpose of transmitting power and reduce the transmission of shock loads from one

shaft to another. The output shaft of spur gearbox is coupled with input shaft of bevel gearbox with the help of sleeve or muff-coupling. This coupling was used because the shafts of both gear boxes were in same line.

4.11. Design of crop conveyor unit

The cut crop is conveyed to one side by the lugged belt conveyor at an angle of 90° for easy collection and bundling. The collecting belt is used to carry cut crops with the aid of lugs sideways. Proper collecting of crop is very important to reduce the grain losses during harvesting. Hence, implementation of collecting mechanism increases the efficiency of harvesting machinery.

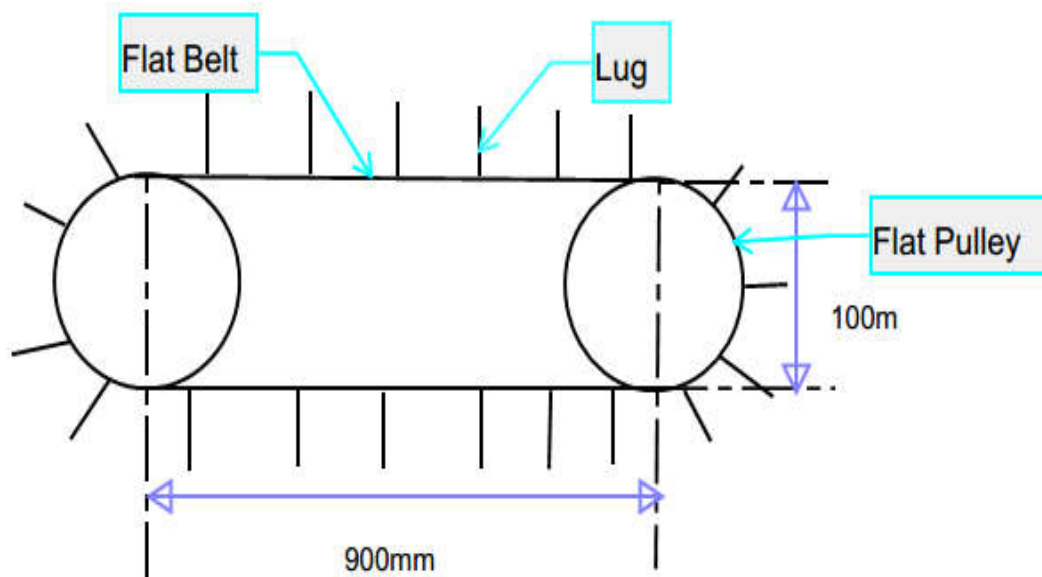


Figure 4.18. Lugged belt conveyor

4.11.1. Dimensions of lugged belt pulleys

The cotton belts are cheaper and suitable in warm climates, in damp atmospheres and in exposed positions. Since the cotton belts require little attention, these belts are mostly used in farm machinery as belt conveyor.

Maximum Tension in the Belt: A little consideration will show that the maximum tension in the belt (T) is equal to the total tension in the tight side of the belt (T_1).

The maximum tension in the belt (T) = Maximum stress $\times$ Cross-sectional area of belt (Khurmi and Gupta, 2005)

$$T = \sigma_{\max} \times b \times t \dots\dots\dots (4.36)$$

$$T = \sigma_{\max} \times b \times t \text{ but, } \sigma_{\max} = \frac{\sigma_{\text{ult}}}{f.s}$$

$$T = \frac{\sigma_{\text{ult}}}{f.s} \times b \times t \dots\dots\dots (4.37)$$

Where, $\sigma_{\max}$ = Maximum safe stress,

b = Width of the belt, and

t = Thickness of the belt

$f.s$ = factor of safety

The standard flat belt thicknesses are 5, 6.5, 8, 10 and 12 mm and the standard widths will be 25, 32, 40, 50, 63, 71, 80, 90, 100, 112, 125, 140, 160, 180, 200, 224, 250, 280, 315, 355, 400, 450, 500, 560 and 600 mm.

If the width of the belt is known, then width of the pulley or face of the pulley (B) is taken 25% greater than the width of belt. $B=1.25b$, where b = width of belt. (Khurmi and Gupta, 2005). For a lugged flat belt the belt speed is given by

$$V_b = \frac{\pi D_p N_p}{60} \dots\dots\dots (4.38)$$

Where, V_b = peripheral speed of flat belt

D_p = diameter of lugged belt pulley, m

N_p = speed of lugged belt pulley, rpm

Diameter of pulley (D_p) is given by the following equation.

$$D_p = \frac{V_b \times 60}{\pi \times N_p} \dots\dots\dots (4.39)$$

Peripheral speed of flat belt can be estimated as, $V_b = 1.33\text{m/s}$ to 1.5 m/s . (Sharma and Mukesh 2010). Let's take $V_b = 1.5 \text{ m/s}$ and $N_p = 312.5 \text{ rpm}$ Since, the drive from the shaft which is used for driving the bevel gear shaft having 312.5 rpm is used to drive the conveyor belts . Here two

pulleys of the same size are used for conveyer belt. The material selected for the pulleys cast iron, because of their low cost. Diameter of pulley from equation above (equation 4.39)

$D_p = \frac{1.5 \times 60}{\pi \times 312.5} = 0.092\text{m} = 91.673\text{mm}$. From standard taking, $D_p = 100\text{mm}$. From equation 4.38, velocity of conveyor belt can be calculated

$$V_b = \frac{\pi \times 0.1 \times 312.5}{60} = 1.636 \text{ m/s}$$

The thickness of the pulley rim (t) varies from $\frac{D_p}{300} + 2$ to $\frac{D_p}{200} + 3$ for single belt (Khurmi and Gupta, 2005). Therefore, substituting values $t = 2.33$ to 3.5mm .

The pulleys less than 200 mm diameter are made with solid disc instead of arms. The thickness of the solid web is taken equal to the thickness of rim measured at the centre of the pulley face. Take belt thickness (t) = 5 mm and $\sigma_{ult} = 35 \text{ Mpa}$, factor of safety (f.s) = 1.5 and using equation (4.37) belt width can be calculated.

Power from engine source is 2.7 kw. Power needed to rotate the conveyor pulley is from engine via different shaft. Assuming 90% power transmission efficiency at each stage and there would be three reduction from engine to cutting and conveying.

So, let's assume $P = 2.7 \times 90\% = 2.43 \text{ kW}$

$$P = (T_1 - T_2) V,$$

$$2.7 \text{ kW} = (T_1 - T_2) 1.5$$

$$T_1 - T_2 = 1.62 \times 10^3 \dots i$$

Taking angle contact (θ) = 3.14 because the diameter of the two pulleys is equal, angle of groove 38° and $\mu = 0.22$

$$2.3 \log \left(\frac{T_1}{T_2} \right) = 0.22 \times 3.14 \text{Cosec} 19$$

$$\log \left(\frac{T_1}{T_2} \right) = 0.923, \text{ By taking antilog of } 0.923$$

$$T_1 = 8.366 T_2 \dots ii$$

Substituting ii in i, $T_1 = 1.84\text{kN}$ and $T_2 = 0.22\text{kN}$

$$1.84\text{kN} = \frac{35}{1.5} \times b \times 5$$

$$b = 21.029\text{mm}$$

Then, belt width (b) = 21.029mm. Therefore, from standard b = 25mm can be selected. Is belt is found it is easy to calculate width or face of pulley (B) = 1.25b. So, B = 31.25mm

4.11.2. Length of lugged belt of conveyor pulley

The length of lugged belt is given by (Khurmi and Gupta, 2005)

$$L = 2C + \pi \frac{D+d}{2} + \frac{(D-d)^2}{4C} \dots\dots\dots (4.40)$$

Where L= length of belt, mm

C= center to distance between lugged belt pulleys, cm

D= diameter of driving pulley, cm

d= diameter of driven pulley, cm

It is calculated based on length of cutter bar and length of vertical plat form required for supporting the crop. Length of cutter bar = 80 cm. Now, center to center distance (C) between driving and driven pulleys is given by

$$C = \frac{10}{2} + 80 + \frac{10}{2} = 90 \text{ cm} = 900\text{mm}$$

The length of flat belt is given by equation (4.40)

$$L = 2 \times 0.9 + \frac{\pi (0.1 + 0.1)}{2} + 0$$

$$L = 1.8 + 0.314 + 0 = 2.114\text{m}$$

The length of flat belt required for lugged belt conveyor would be 2114mm

4.11.3. Number of lugs on belt

The number of lugs on conveyor belt is given by (Sharma and Mukesh 2010)

$$N_l = \frac{L}{P_l} \dots\dots\dots (4.41)$$

Where, N_l = Number of lug on belt

L = length of belt, mm

P_l = pitch of lugs, mm

To have good collecting mechanism, let pitch of lugs on the belt is $p = 100\text{mm}$. According to (Sharma and Mukesh, 2010) by number of lugs on conveyor belt $= N_l = \frac{L}{p_l}$, $N_l = \frac{2114}{100} = 21.140$, take number of lugs 22. Material selected for the lug is aluminum because it is light weight. Adjusted length of belt $= P \times \text{number of lugs} = 100 \times 22 = 2200 \text{ mm}$

4.11.4. Lug height determination

The lug height should be such that the branches of cut crop can be conveyed continuously without any blockage. This is only possible when conveyor output per unit time is greater than equal to cutter output. (Sharma and Mukesh, 2005). That means, output of conveyor $\geq$ cutter bar output

$$h. W. \rho_2 \geq \rho_1. W_2. \frac{V_m}{V_c} \dots\dots\dots(4.42)$$

$$h \geq \rho_1. W_2. \frac{V_m}{\rho_2} W V_c, \text{ Take } \frac{\rho_2}{\rho_1} = q = \frac{A_1}{A_2} \text{ then}$$

$$h \geq \left(\frac{W}{q}\right) \times \left(\frac{V_m}{V_c}\right) \dots\dots\dots(4.43)$$

Where, h = height of lug, cm

W = cutting width, cm

V_m = machine speed, m/s

V_c = Conveyor belt speed, m/s

ρ_1 = density of crop plants in field

ρ_2 = density of cut crop on vertical platform

q = gathered crop parameter $= \rho_2 / \rho_1 = A_1 / A_2$

A_1 = one m^2 area in the field

A_2 = area of circle of bunched cut crop from 1m^2 area in the field

$$\text{Also } q = 4\pi C^2$$

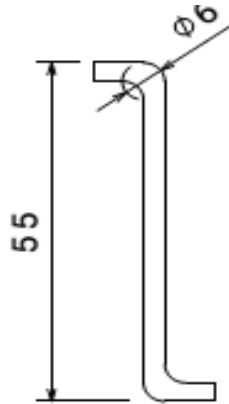
C = circumference of the cut crop bunch whose area is A_2

According to (D.N. Sharma and S. Mukesh, 2010), For wheat crop: $A_2 = 1.5 \times 10 - 5 \times 500 = 0.0075 \text{ m}^2 = 0.01 \text{ m}^2$. Putting the values of A_1 and A_2 , q can be calculated $q = \frac{1}{0.01} = 100$.

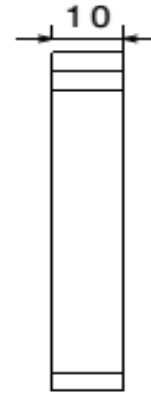
Putting values in equation (4.43), height of lug can be calculated as follows

$$h \geq \left(\frac{80}{100}\right) \times \left(\frac{0.8}{1.5}\right) \geq 0.427\text{cm} = 4.27\text{mm}$$

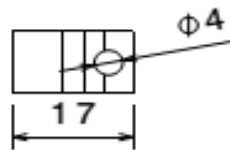
The cutter blade acts as a cutting and crop dividing unit in thesis compact harvester. Therefore, a clearance between flat belt pulley and tip of cutter blade is 50mm. the height of lug (h) = 4.27mm + 50mm = 54.27mm. Hence, lug on conveyor belt is kept as, h = 55mm.



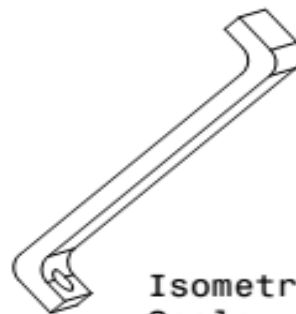
Front view
Scale: 1:1



Left view
Scale: 1:1



Top view
Scale: 1:1



Isometric view
Scale: 1:1

Figure 4.19. Front, top, side view and Isometric view of lug respectively

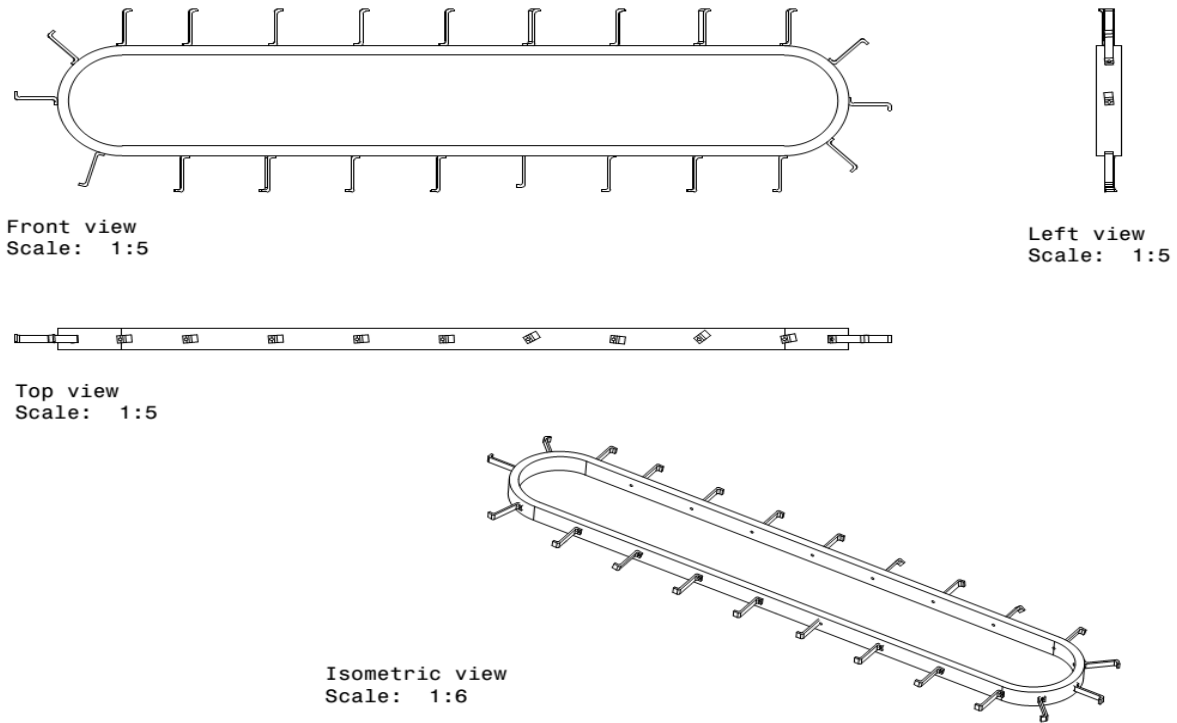


Figure 4.20. Lug with conveyor belt

Table 4.3. Specification for crop conveyor

No.	Particulars	Specifications
1	Speed of lugged belt(V_b)	1.5 m/s
2	Diameter of pulley(D_p)	100mm
3	Length of lugged belt(L_b)	2200mm
4	Pitch of lugs(P_l)	100 mm
5	Lug height(h)	55 m

4.12. Assembling all parts of reaper by using CATIAV5R17 software

All the components are going to be brought together and then bolted on the frame. First engine is mounted on the frame using bolts and nuts. Then spur gear box is bolted to the frame, and with the help of pulley system engine and spur gear box is connected. Then the bevel and spur gear box is connected together using muff-coupling. This coupling was used because the shafts of both gear boxes were in same line. To the output shaft of the bevel gear box is connected to collecting mechanism using belt-pulley system. To the other end of output shaft of bevel gear box cutting mechanism is connected using slider crank mechanism. The designed and analyzed machine has the following model prototype by CATIA V5R17 software.

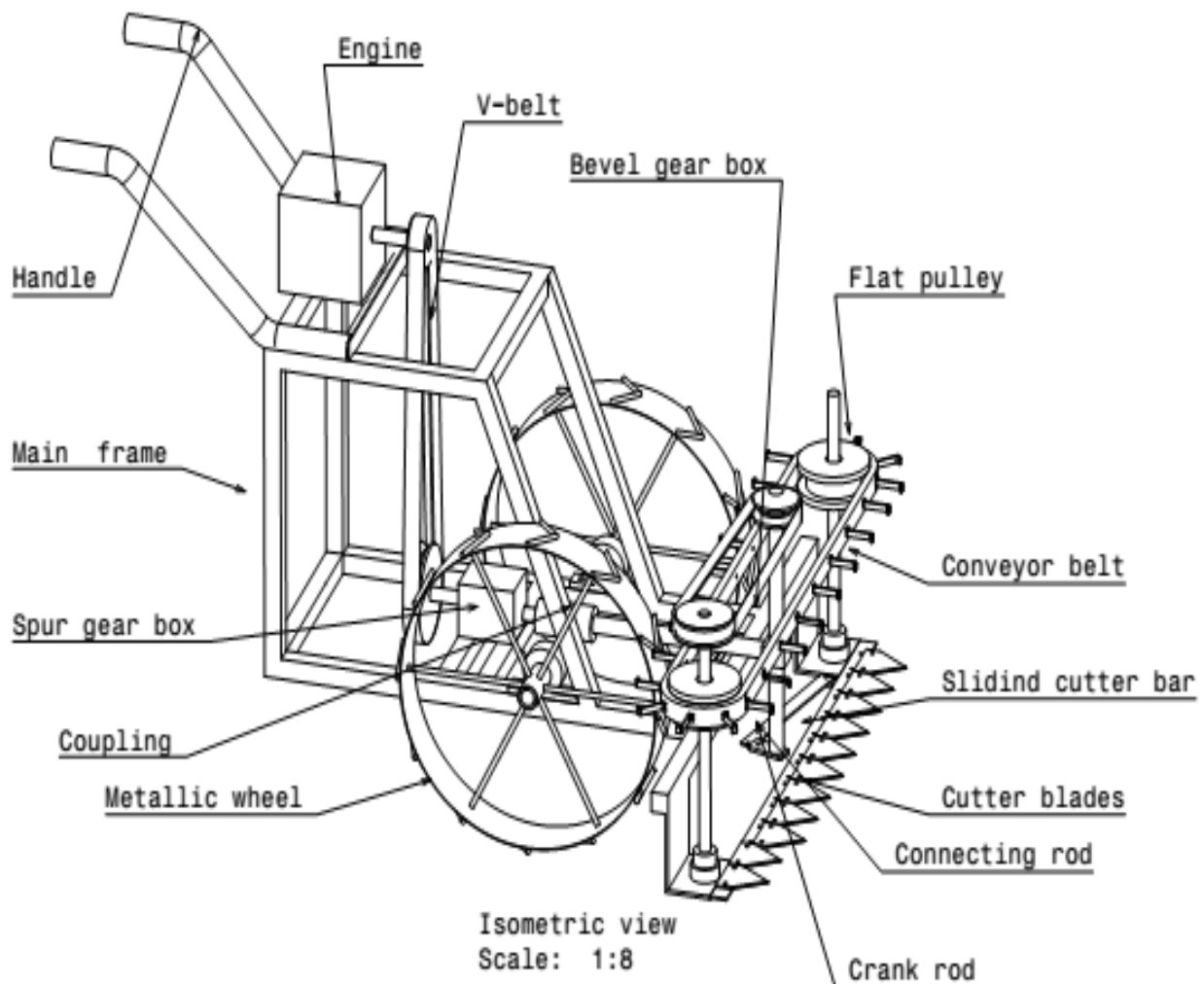


Figure 4.21. 3D model of wheat crop Reaper

4.13. Cost Analysis

Table 4.4. Cost of wheat crop Reaper

No	Part required	Unit	Quantity	Unit cost	Total cost
1	V-belts	1. L= 1636mm	1	295	295
		2. L =1103mm	1	260	260
2	Pulleys(v-belt pulleys)	1.D = 250mm	1	365	365
		2.D = 125mm	1	300	300
		3.D = 80mm	1	285	285
		4.D = 90mm	1	290	290
3	Angle iron	Meter	1	41	41
4	Axle	Meter	2	205	410
5	Bearing circlips	Pcs	12	20	240
6	Bearings	Pcs	15	235	3525
7	Bevel gear box	Item	1	1950	1950
8	Bolts and nuts	Pcs	24	25	600
9	Conveyor belt	L = 2200mm	1	355	355
10	Conveyor pulley	D = 100mm	2	365	730
11	Coupling	Item	1	595	595
12	Cutter bar	Square meter	2	105	210
13	Cutter blades	Pcs	20	125	2500
14	Diesel engine	Item	1	9500	9500
15	Lugs	Item	22	75	1650
16	Metal for wheel assembly	Square meter	1	355	355
17	Round bar	Meter(D=8mm)	1	242	242
18	Round bar for handle	Meter	2	95	190
19	Shaft	Meter	3	285	849
20	Spur gear box	Item	1	1873	1873
21	Square bar for main frame	Square meter	1	880	880
Total cost					28,485 Birr

CHAPTER FIVE

CONCLUSION AND FUTURE WORK

5.1. Conclusion

The harvesting machines used in the world aren't suitable for the small scale farmers. The harvesters available in market are suitable for large farms. Small scale farmers mean those who have farming area less than 2 hectares. That means use of combine harvester is not compatible and affordable for individual small scale farmers. Farmers in vertisol areas are using their land for wheat crop productions mainly by using BBM technology which drains excess water from their farm land.

To solve the above problem the designed and developed reaper in this paper has ability to cut wheat crops stems up to 0.8m furrow width. That means, the newly designed and developed reaper fits for BBF prepared with BBM which makes 0.8m wide furrows. This machine also helps to harvest from traditional furrows other than Broad Bed Furrows. The reaper is designed to cut wheat crops at the height of 100 mm from the ground level, for the reason that the farmer needs the straw as an important by product for animal feeds and other purposes. Generally, the developed wheat reaper is best for harvesting wheat crops for the farmers with small land holders.

The detailed design and analysis of wheat crop reaper which includes main frame assembly, cutting mechanism systems, conveying unit and power transmission system from the engine to spur gear box, bevel gear box and to the cutter bar assembly has been carried out. The 2D and 3D model of the wheat crop reaper components were generated using CATIAV5R17 software to aid the fabrication of the designed reaper in the future.

The design specification for the wheat crop reaper was created based on design parameter calculated values and analysis to meet the requirements of wheat crop reaper from BBF. After entirely manufacture the reaper, this machine is to be compact and efficient to cut the wheat crops. The machine is moderately compact and easy to handle. This machine is able to run of field easily and the efforts of farmers are reduced. The success of this machine after its fabrication depends on how the farmers receive this machine as their supporter. There are some

changes that need to be done on the machine and a final product is to be taken out for distributing to the small scale farmers.

5.2. Future work

Because of the limitation of budget, this paper does not include the manufacture and testing of the machine. It simply addresses necessary design and analysis information. To keep the machine quality the following work will need additional attention.

- Check either the wheat crop stems are cut properly by cutting unit of cutter bar assembly.
- Analyses vibration effect and find the solution if there is an effect.
- Check either weight balance is needed. If weight balance needed for this machine find the way it can be solved.
- Finite element analysis with ANSYS soft ware for selected component need to be done.
- After all the above limitation checked the reaper has to be manufactured and tested for its working satisfactorily and distributed for local farmers with affordable cost.
- Further study, for more improvement in order to make the machine compact, light, effective and simple for less skilled or unskilled small scale farmers.

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APPENDIXES

Appendix 1: Recommended values for K_m and K_t

Nature of load	K_m	K_t
1. Stationary shafts		
a. Gradually applied load	1.0	1.0
b. Suddenly applied load	1.5 -2.0	1.5-2.0
2. Rotating shafts		
a. Gradually applied or steady load	1.5	1.0
b. Suddenly applied load with minor shocks	1.5-2.0	1.5-2.0
c. Suddenly applied load with heavy shocks	2.0-3.0	1.5-3.0

Appendix 2: coefficient of friction between belt and pulley

Belt material	Pulley material						
	Cast iron, steel			Wood	Compressed paper	Leather face	Rubber face
	Dry	Wet	Greasy				
1. Leather oak tanned	0.25	0.2	0.15	0.3	0.33	0.38	0.40
2. Leather chrome tanned	0.35	0.32	0.22	0.4	0.45	0.48	0.50
3. Convass-stitched	0.20	0.15	0.12	0.23	0.25	0.27	0.30
4. Cotton woven	0.22	0.15	0.12	0.25	0.28	0.27	0.30
5. Rubber	0.30	0.18	—	0.32	0.35	0.40	0.42
6. Balata	0.32	0.20	—	0.35	0.38	0.40	0.42

Appendix 3: Dimension of standard v-belts and v-grooved pulleys (all dimensins in mm)

Type of belt	Power ranges in kW	Minimum pitch diameter of pulley (D) mm	Top width (b) mm	Thickness (t) mm	Weight per metre length in newton
A	0.7 – 3.5	75	13	8	1.06
B	2 – 15	125	17	11	1.89
C	7.5 – 75	200	22	14	3.43
D	20 – 150	355	32	19	5.96
E	30 – 350	500	38	23	—

Type of belt	<i>w</i>	<i>d</i>	<i>a</i>	<i>c</i>	<i>f</i>	<i>e</i>	No. of sheave grooves (<i>n</i>)	Groove angle (2β) in degrees
<i>A</i>	11	12	3.3	8.7	10	15	6	32, 34, 38
<i>B</i>	14	15	4.2	10.8	12.5	19	9	32, 34, 38
<i>C</i>	19	20	5.7	14.3	17	25.5	14	34, 36, 38
<i>D</i>	27	28	8.1	19.9	24	37	14	34, 36, 38
<i>E</i>	32	33	9.6	23.4	29	44.5	20	–

Note : Face width (*B*) = (*n* – 1) *e* + 2 *f*

Appendix 4: Coefficient of friction between belt and pulley

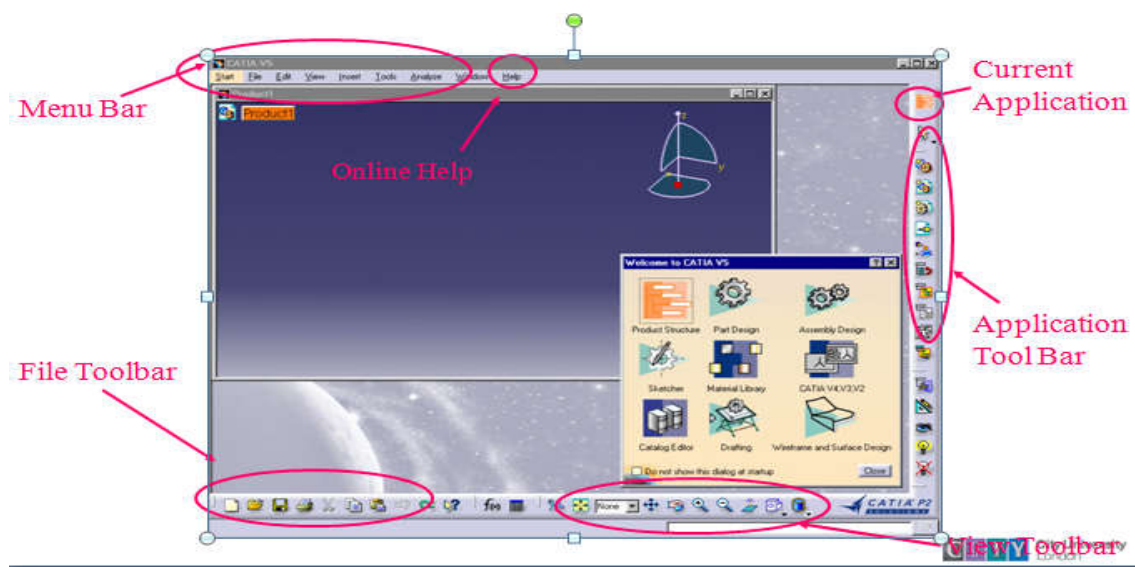
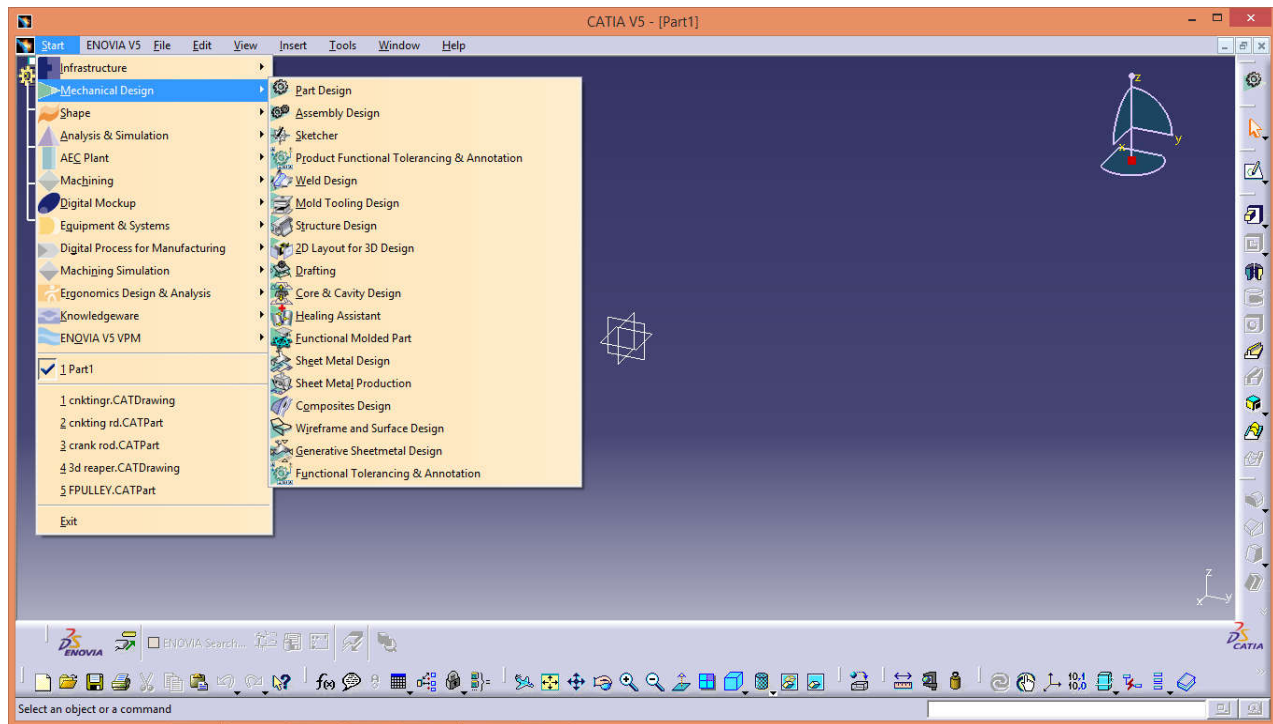
Belt material	Pulley material						
	Cast iron, steel			Wood	Compressed paper	Leather face	Rubber face
	Dry	Wet	Greasy				
1. Leather oak tanned	0.25	0.2	0.15	0.3	0.33	0.38	0.40
2. Leather chrome tanned	0.35	0.32	0.22	0.4	0.45	0.48	0.50
3. Convass-stitched	0.20	0.15	0.12	0.23	0.25	0.27	0.30
4. Cotton woven	0.22	0.15	0.12	0.25	0.28	0.27	0.30
5. Rubber	0.30	0.18	—	0.32	0.35	0.40	0.42
6. Balata	0.32	0.20	—	0.35	0.38	0.40	0.42

Appendix 5: Standard pitch lengths of V-belts

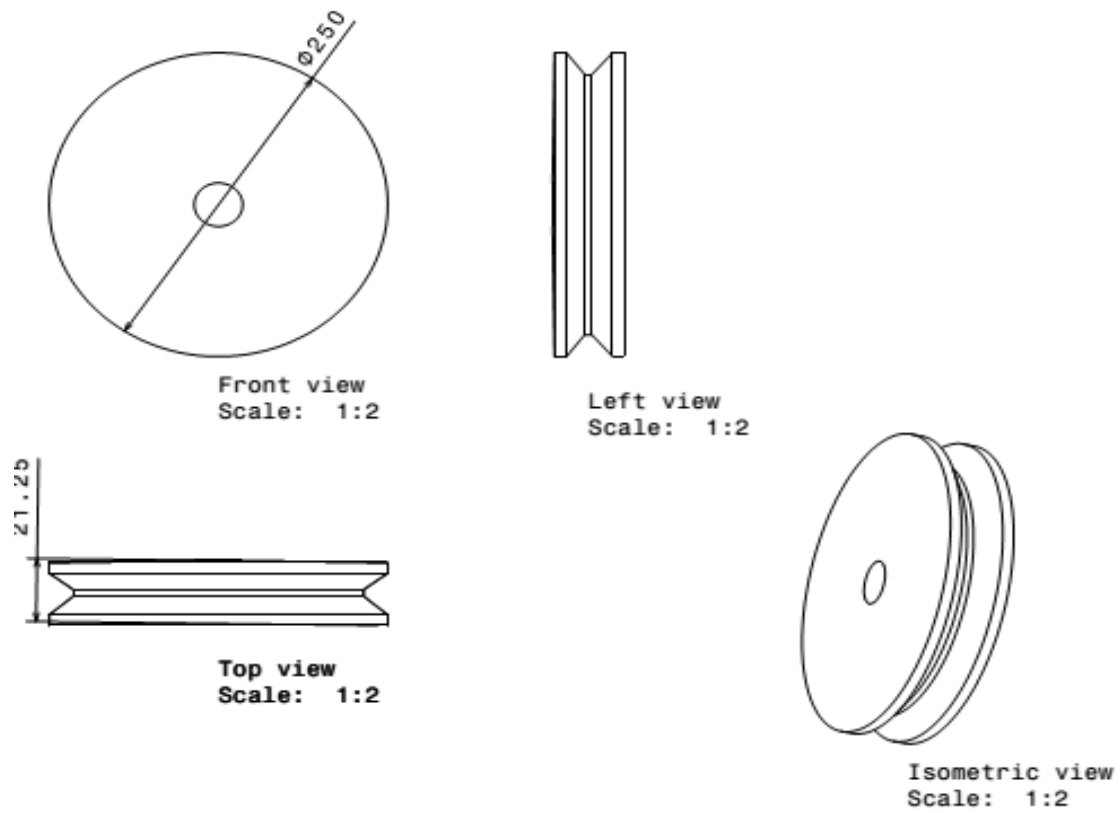
Type of belt	Standard pitch lengths of V-belts in mm
<i>A</i>	645, 696, 747, 823, 848, 925, 950, 1001, 1026, 1051, 1102 1128, 1204, 1255, 1331, 1433, 1458, 1509, 1560, 1636, 1661, 1687, 1763, 1814, 1941, 2017, 2068, 2093, 2195, 2322, 2474, 2703, 2880, 3084, 3287, 3693.
<i>B</i>	932, 1008, 1059, 1110, 1212, 1262, 1339, 1415, 1440, 1466, 1567, 1694, 1770, 1821, 1948, 2024, 2101, 2202, 2329, 2507, 2583, 2710, 2888, 3091, 3294, 3701, 4056, 4158, 4437, 4615, 4996, 5377.
<i>C</i>	1275, 1351, 1453, 1580, 1681, 1783, 1834, 1961, 2088, 2113, 2215, 2342, 2494, 2723, 2901, 3104, 3205, 3307, 3459, 3713, 4069, 4171, 4450, 4628, 5009, 5390, 6101, 6863, 7625, 8387, 9149.
<i>D</i>	3127, 3330, 3736, 4092, 4194, 4473, 4651, 5032, 5413, 6124, 6886, 7648, 8410, 9172, 9934, 10 696, 12 220, 13 744, 15 268, 16 792.
<i>E</i>	5426, 6137, 6899, 7661, 8423, 9185, 9947, 10 709, 12 233, 13 757, 15 283, 16 805.

Appendix 5: CATIAV5R17 soft ware and some parts generated

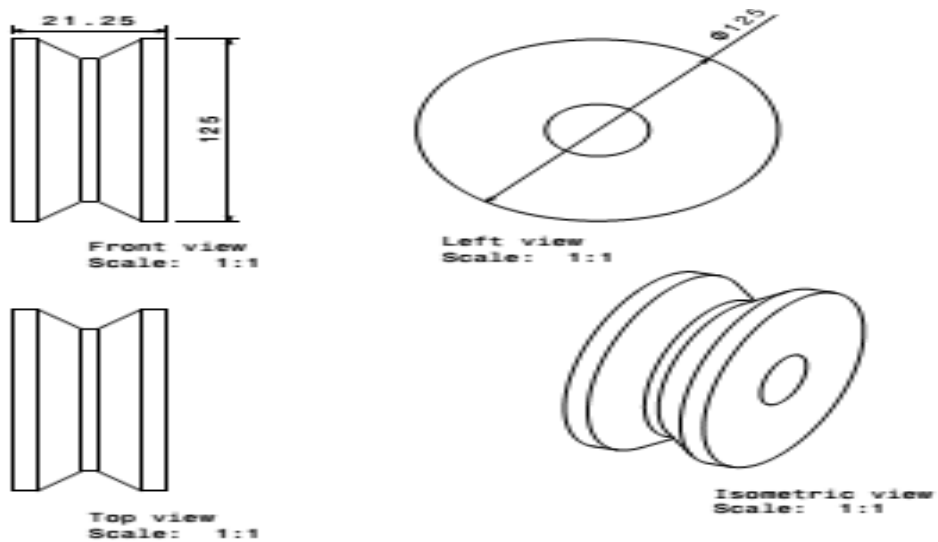
One of the world's leading parametric solid modeling techniques enhances the productivity and efficiency of the user. CATIAV5R17 is structured in pedagogical sequence, covering the Part, Assembly, Drafting and Generative design work bench.



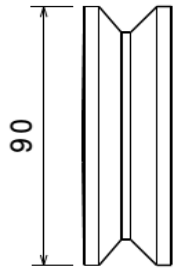
1. Front, top, side view and Isometric view of large pulley respectively



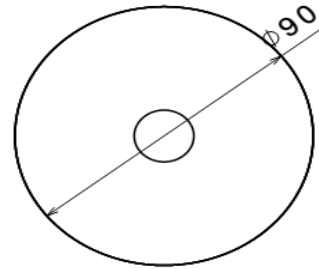
2. Front, top, side view and Isometric view of small pulley respectively



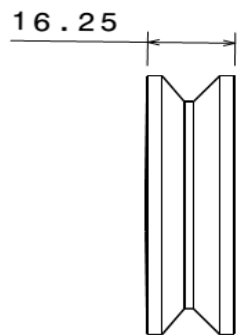
3. Front, top, side view and Isometric view of large pulley respectively



Front view
Scale: 1:2



Left view
Scale: 1:2

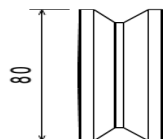


Top view
Scale: 1:2

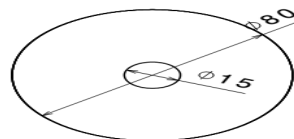


Isometric view
Scale: 1:2

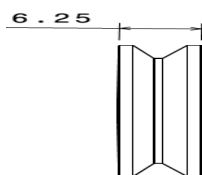
4. Front, top, side view and Isometric view of small pulley respectively



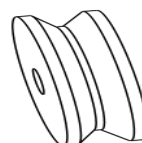
Front view
Scale: 1:2



Left view
Scale: 1:2

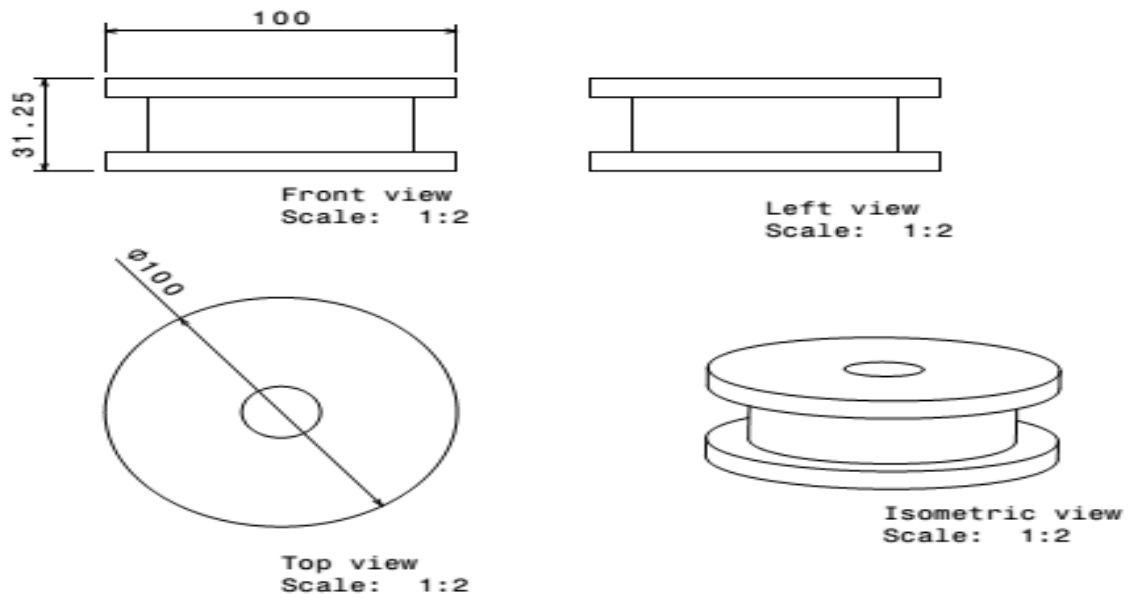


Top view
Scale: 1:2



Isometric view
Scale: 1:2

5. Front, top, side view and Isometric view of flat pulley respectively



6. Figure 4.30: Front, top, side view and Isometric view of support for flat belt respectively

